



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

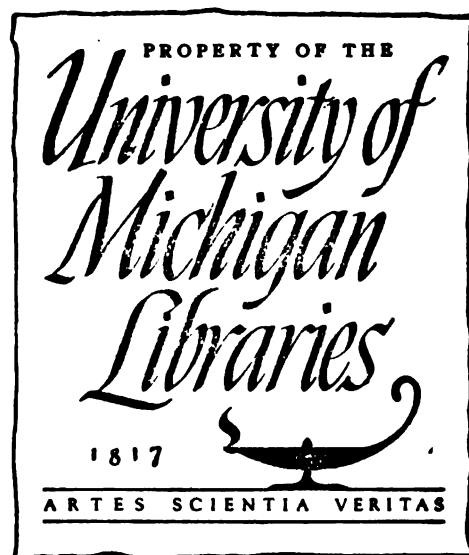
We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>

C 481,413



Q
41
L8
P6

v.123

5185

PHILOSOPHICAL
T R A N S A C T I O N S
OF THE
R O Y A L S O C I E T Y
OF
L O N D O N.

FOR THE YEAR MDCCCXXXIII.

PART II. *MC 123*

LONDON:

PRINTED BY RICHARD TAYLOR, RED LION COURT, FLEET STREET.

MDCCCXXXIII.

C O N T E N T S.

- XII. *Magnetical Experiments made principally in the South part of Europe and in Asia Minor, during the years 1827 to 1832. By the Rev. GEORGE FISHER, A.M., F.R.S.* page 237
- XIII. *Researches on the Arseniates, Phosphates, and Modifications of Phosphoric Acid. By THOMAS GRAHAM, Esq., M.A., F.R.S.E., Professor of Chemistry in the Andersonian University of Glasgow. Communicated by EDWARD TURNER, M.D., F.R.S.* 253
- XIV. *On the influence of Colour on Heat and Odours. By JAMES STARK, M.D., of Edinburgh. Communicated by Sir DAVID BREWSTER, K.H., F.R.S.* 285
- XV. *Experimental Researches in Electro-Magnetism and Magneto-Electricity. By the Rev. WILLIAM RITCHIE, LL.D., F.R.S., Professor of Natural Philosophy at the Royal Institution of Great Britain and in the University of London* 313
- XVI. *On the Anatomical and Optical Structure of the crystalline Lenses of Animals, particularly that of the Cod. By Sir DAVID BREWSTER, LL.D., F.R.S. V.P.R.S. Ed.* 323
- XVII. *On the magnetic powers of Soft Iron. By Mr. FRANCIS WATKINS. Communicated by J. G. CHILDREN, Esq., Sec. R.S.* 333
- XVIII. *On Improvements in the Instruments and Methods employed in determining the direction and intensity of the Terrestrial Magnetic Force. By S. HUNTER CHRISTIE, Esq., M.A., F.R.S. M.C.P.S. Soc. Philom. Paris. Corresp.* 343
- XIX. *Observations of Nebulæ and Clusters of Stars, made at Slough, with a*

- Twenty-feet Reflector, between the years 1825 and 1833. By Sir JOHN FREDERICK WILLIAM HERSCHEL, Knt. Guelp., F.R.S. . . . page 359*
- XX. *Experimental Researches in Electricity.—Fourth Series. By MICHAEL FARADAY, D.C.L., F.R.S. M.R.I., Fullerian Prof. Chem. Royal Institution, Corr. Memb. Royal Acad. of Sciences, Paris, Petersburg, Florence, Copenhagen, Berlin 507*
- XXI. *Experimental Researches on Atomic Weights. By EDWARD TURNER, M.D., F.R.S. Lond. & Ed., Sec. G.S., Professor of Chemistry in the University of London 523*
- XXII. *Note on a Paper by Dr. JOHN DAVY, entitled "Notice on the remains of the recent Volcano in the Mediterranean." By CHARLES DAUBENY, M.D., F.R.S., Professor of Chemistry in the University of Oxford . . 545*
- XXIII. *Observations of the Comet of Encke, made in June 1832. By THOMAS HENDERSON, Esq., His MAJESTY'S Astronomer at the Cape of Good Hope. Communicated, by Command of the Lords Commissioners of the Admiralty, by Captain BEAUFORT, R.N., F.R.S., Hydrographer to the Admiralty 549*
- XXIV. *On the development of the disturbing Function, upon which depend the inequalities of the motions of the Planets, caused by their mutual attraction. By JAMES IVORY, K.H., M.A., F.R.S., Instit. Reg. Sc. Paris. Corresp. et Reg. Sc. Götting. Corresp. 559*
- XXV. *On the Figures obtained by strewing Sand on Vibrating Surfaces, commonly called Acoustic Figures. By CHARLES WHEATSTONE, Esq. Communicated by MICHAEL FARADAY, Esq., D.C.L., F.R.S. 593*
- XXVI. *On the Reflex Function of the Medulla Oblongata and Medulla Spinalis. By MARSHALL HALL, M.D., F.R.S. L. & E. 635*
- XXVII. *On the present Situation of the Magnetic Lines of equal variation, and their Changes on the Terrestrial Surface. By PETER BARLOW, Esq., F.R.S., Corr. Memb. Inst. France, and of the Imp. and Royal Academies of Petersburg, Brussels 667*
- XXVIII. *Experimental Researches in Electricity.—Fifth Series. By MICHAEL FARADAY, D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Corr. Memb. Royal and Imp. Acad. of Sciences, Paris, Petersburg, Florence, Copenhagen, Berlin 675*

- XXIX. *The Anatomy and Physiology of the Liver.* By FRANCIS KIERNAN, Esq.,
Member of the Royal College of Surgeons, late Teacher of Anatomy.
Communicated by Joseph Henry GREEN, Esq., F.R.S. . . . page 711
- XXX. *Some Observations on the Economy of Molluscous Animals, and on the
Structure of their Shells.* By JOHN EDWARD GRAY, Esq., F.R.S. . 771
- Index*

APPENDIX.

*Meteorological Journal kept at the Apartments of the Royal Society, by order
of the President and Council.*

ERRATA.

Page 144, line 28, *for* absolvable *read* absorbable.

— 146, — 9, *for* or *read* on.

— 281, *for* a terphosphate, a biphosphate, and phosphate of water, *read* a terhydrate, a bihydrate,
and hydrate of phosphoric acid.

In Plate XIX. *for* p. 726. *read* p. 678.

A List of Public Institutions and Individuals, entitled to receive a copy of the Philosophical Transactions of each year, on making application for the same directly or through their respective agents, within five years of the date of publication.

In the British Dominions.

The King's Library.
 The British Museum.
 Sion College Library.
 The Bodleian Library, Oxford.
 The Radcliffe Library, Oxford.
 The Cambridge University Library.
 The Edinburgh College Library.
 Advocates' Library, Edinburgh.
 The University of Glasgow.
 The University of Aberdeen.
 The University of St. Andrews.
 The University of Trinity College, Dublin.
 The Library of King's Inn, Dublin.
 The Royal College of Physicians.
 The Society of Antiquaries.
 The Linnean Society.
 The Royal Institution of Great Britain.
 The Society for the Encouragement of Arts.
 The Geological Society.
 The Horticultural Society.
 The Royal Astronomical Society.
 The Royal Asiatic Society.
 The Medical and Chirurgical Society.
 The London Institution.
 The Cambridge University Philosophical Society.
 The Royal Society of Edinburgh.
 The Royal Irish Academy.
 The Royal Dublin Society.
 The Asiatic Society at Calcutta.
 The Royal Artillery Library at Woolwich.
 The Royal Observatory at Greenwich.
 The Observatory at Dublin.
 The Observatory at Armagh.
 The Observatory at the Cape of Good Hope.
 The Observatory at Madras.
 The Observatory at St. Helena.
 The Observatory at Paramatta.

Denmark.

The Royal Society of Sciences at Copenhagen.
 The Royal Observatory at Altona.

France.

The Royal Academy of Sciences at Paris.
 The Royal Academy of Sciences at Thoulouse.
 The *E'cole des Mines* at Paris.
 The Geographical Society at Paris.
 The Entomological Society of France.

Germany.

The University at Göttingen.
 The Cæsarean Academy of Naturalists at Bonn.
 The Observatory at Manheim.

Italy.

The Italian Society of Sciences at Modena.
 The Royal Academy of Sciences at Turin.

Switzerland.

The *Société de Phys. et d'Hist. Nat.* at Geneva.

Belgium.

The Royal Academy of Sciences at Brussels.

Spain.

The Royal Observatory at Cadiz.

Portugal.

The Royal Academy of Sciences at Lisbon.

Prussia.

The Royal Academy of Sciences at Berlin.

Russia.

The Imperial Academy of Sciences at St. Petersburg.

Sweden and Norway.

The Royal Academy of Sciences at Stockholm.
 The Royal Society of Sciences at Drontheim.

United States.

The American Philosophical Society at Philadelphia.
 The New York Philosophical Society.
 The American Academy of Sciences at Boston.
 The Library of Harvard College.
 The fifty Foreign Members of the Royal Society.

A List of Public Institutions and Individuals, entitled to receive a copy of the Astronomical Observations made at the Royal Observatory at Greenwich, on making application for the same directly or through their respective agents, within five years of the date of publication.

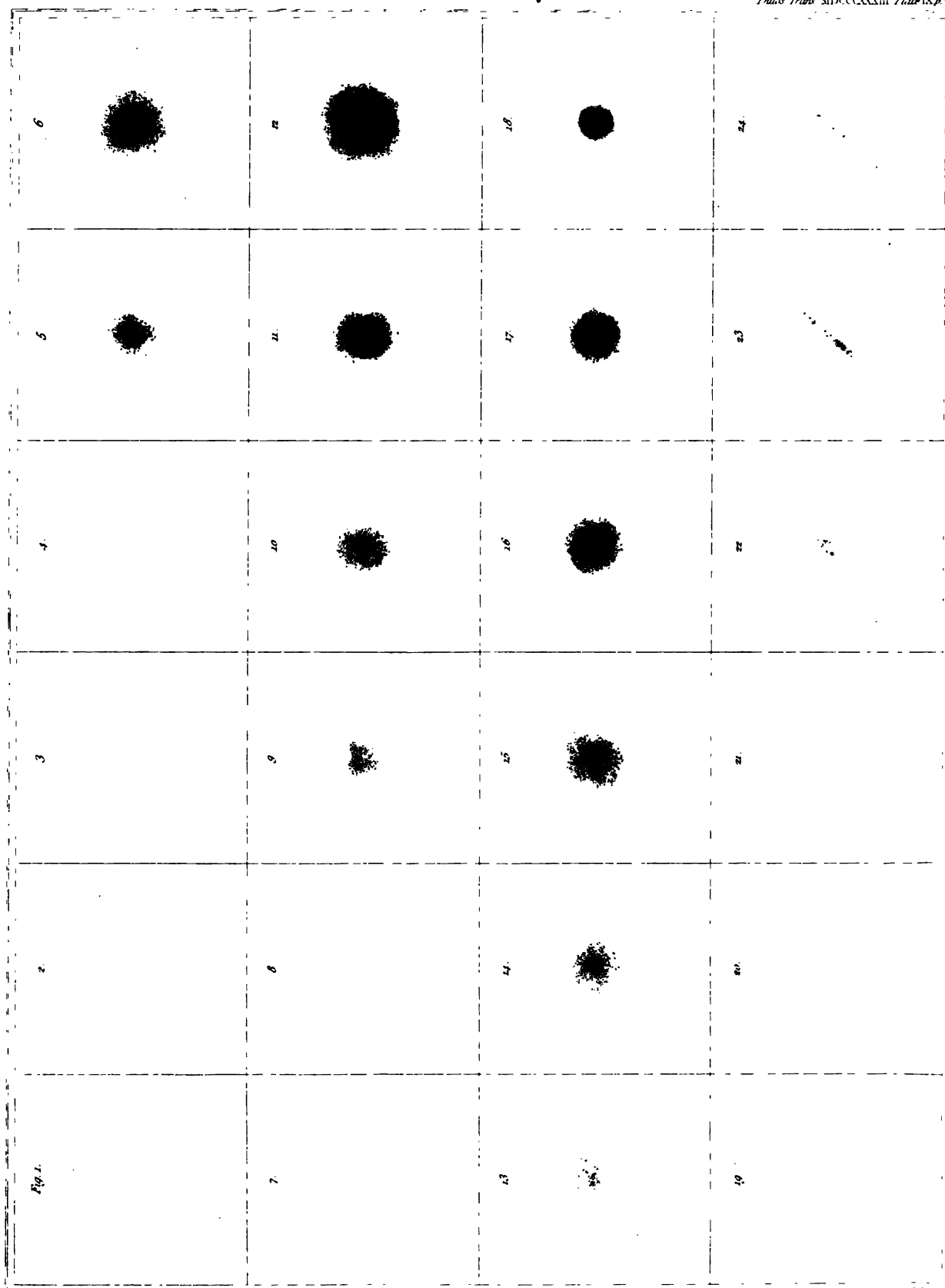
In the British Dominions.

The King's Library.
The Board of Ordnance.
The British Museum.
The Royal Society.
The Bodleian Library, Oxford.
The Savilian Library, Oxford.
The Library of Trinity College, Cambridge.
The King's Observatory at Richmond.
The Royal Observatory at Greenwich.
The University of Aberdeen.
The University of St. Andrews.
The University of Dublin.
The University of Edinburgh.
The University of Glasgow.
The Observatory at Oxford.
The Observatory at Cambridge.
The Observatory at Dublin.
The Observatory at Armagh.
The Observatory at the Cape of Good Hope.
The Observatory at Paramatta.
The Observatory at Madras.
The Observatory at St. Helena.
The Royal Astronomical Society.
The Royal Institution of Great Britain.
The Royal Society, Edinburgh.
The Astronomical Institution, Edinburgh.
The President of the Royal Society.
The Lowndes's Professor of Astronomy, Cambridge.
The Plumian Professor of Astronomy, Cambridge.
The Lord Bishop of Cloyne.
Francis Baily, Esq.
Thomas Henderson, Esq. of Edinburgh.
The Rev. Thomas John Hussey.
John William Lubbock, Esq. V.P. and Treas. R.S.
Captain W. H. Smyth, R.N. of Bedford.
Sir James South.

Lieutenant Stratford, R.N.
Mr. Thomas Taylor, Greenwich.
Edward Troughton, Esq.

In Foreign Countries.

The Royal Academy of Sciences at Berlin.
The Royal Academy of Sciences at Paris.
The Imperial Academy of Sciences at St. Petersburg.
The Royal Academy of Sciences at Stockholm.
The Royal Academy of Sciences at Upsal.
The Board of Longitude of France.
The University of Göttingen.
The University of Leyden.
The Academy of Bologna.
The American Academy of Sciences at Boston.
The American Philosophical Society at Philadelphia.
The Library of Harvard College.
The Observatory at Åbo.
The Observatory at Altona.
The Observatory at Berlin.
The Observatory at Brussels.
The Observatory at Cadiz.
The Observatory at Coimbra.
The Observatory at Copenhagen.
The Observatory at Dorpat.
The Observatory at Königsberg.
The Observatory at Mannheim.
The Observatory at Marseilles.
The Observatory at Milan.
The Observatory at Palermo.
The Observatory at Paris.
The Observatory at Seeberg.
The Observatory at Vienna.
The Observatory at Wilna.
Professor Bessel, of Königsberg.
Dr. William Olbers, of Bremen.



See J. N. H. Herschel's list

W. R. B. 1833

Fig. 25.



Fig. 26.

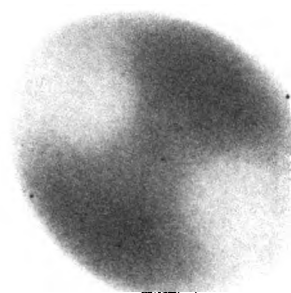


Fig. 27.



Fig. 28.

Fig. 29.



Fig. 30.



Fig. 31.



Fig. 32.



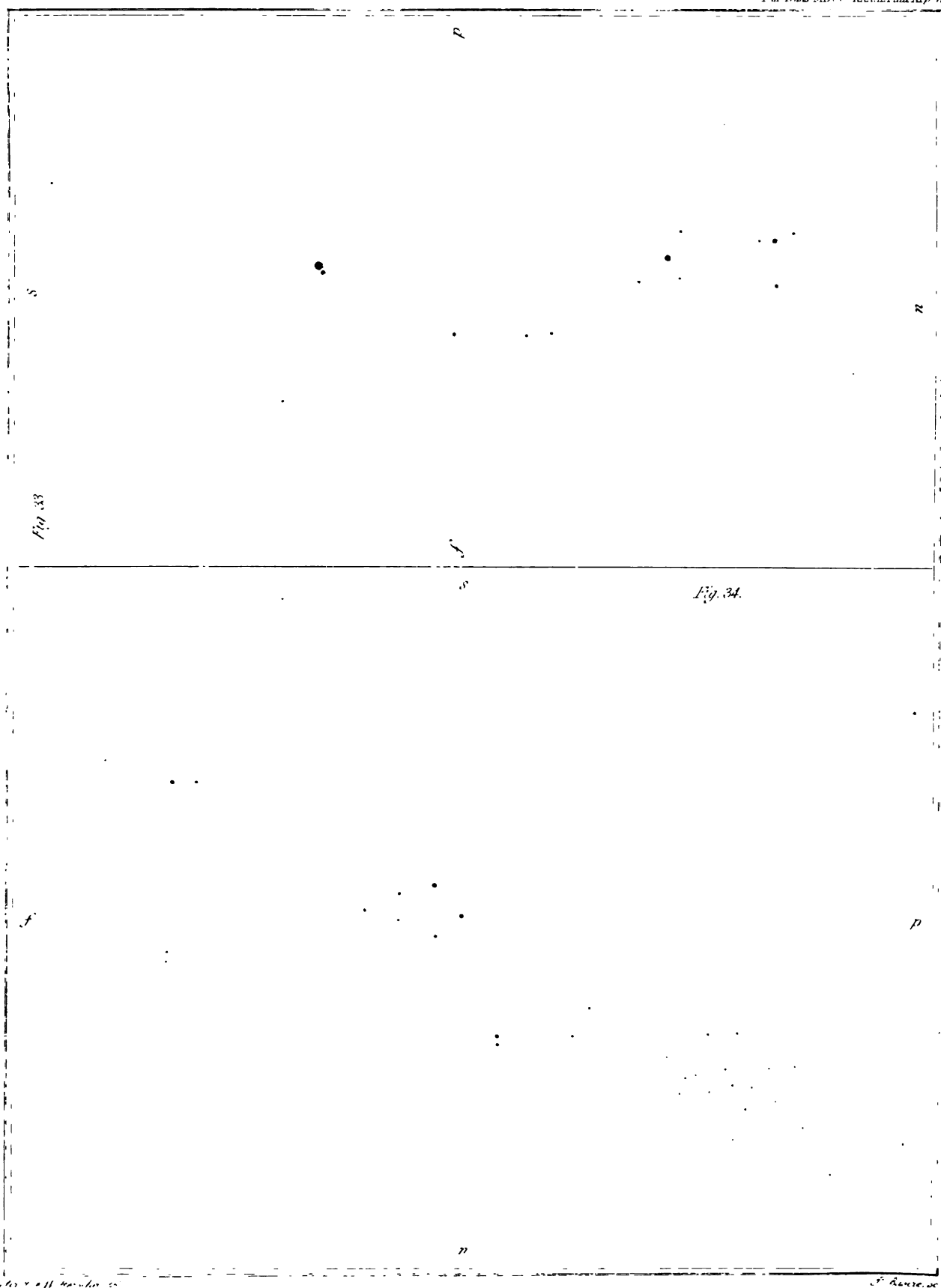


Fig. 35.

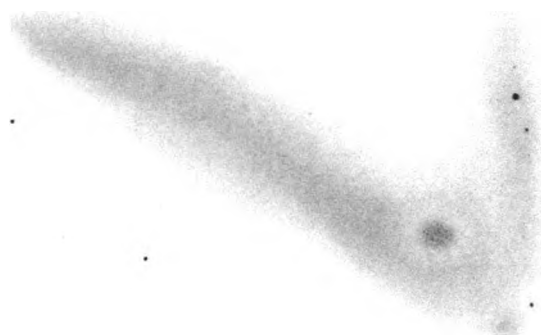


Fig. 36.

Fig. 37.



Fig. 38.

.

Fig. 39.



Fig. 40.



Fig. 41.



Fig. 42.



Fig. 43.



Fig. 44.



Fig. 45.



Fig. 46.



Fig. 47.



Fig. 48.

Fig. 49.



Fig. 50.



Fig. 51.



Fig. 52.



Fig. 53.

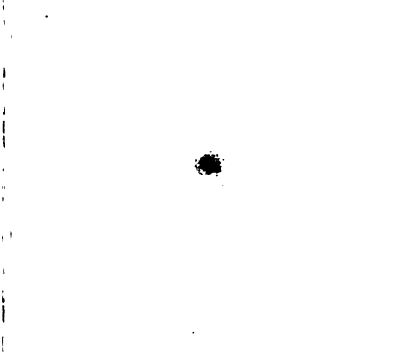


Fig. 54.

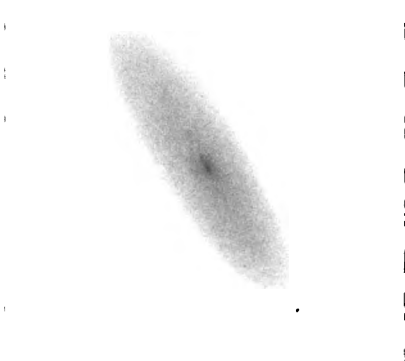


Fig. 55.

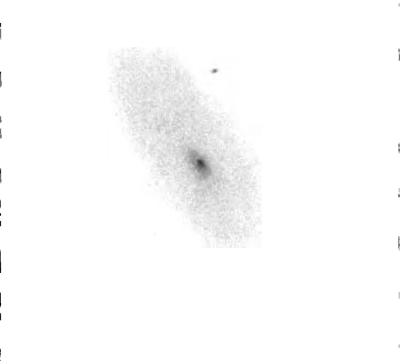


Fig. 56.



Fig. 57.

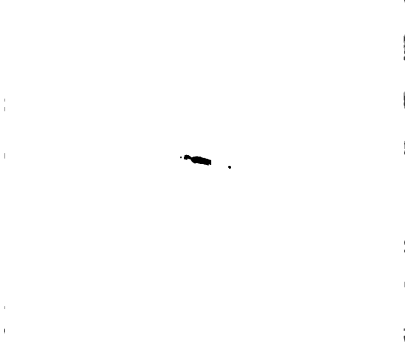


Fig. 58.



Fig. 59.



Fig. 60.

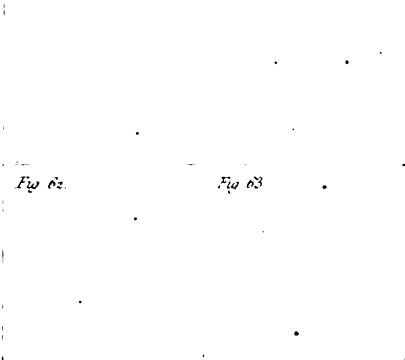


Fig. 61.

Fig. 62.

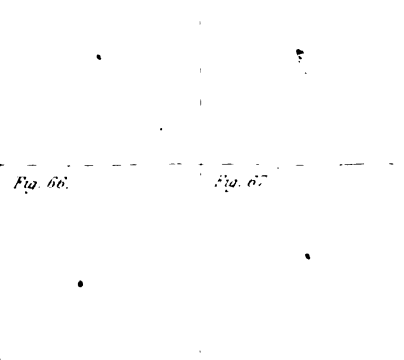


Fig. 63.

Fig. 64.



Fig. 65.

Fig. 66.



Fig. 67.

Fig. 50.

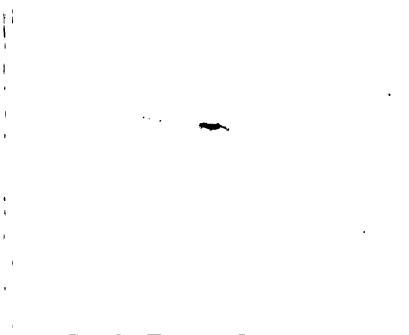


Fig. 51.



Fig. 52.



Fig. 53.

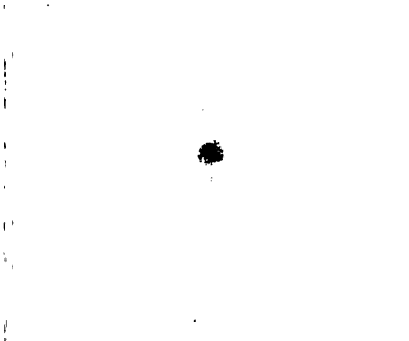


Fig. 54.

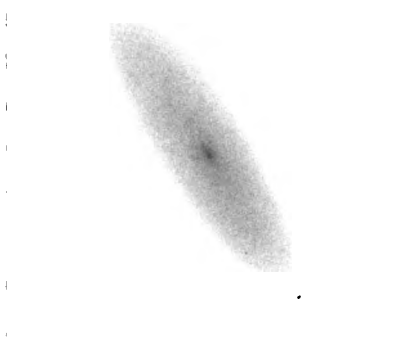


Fig. 55.

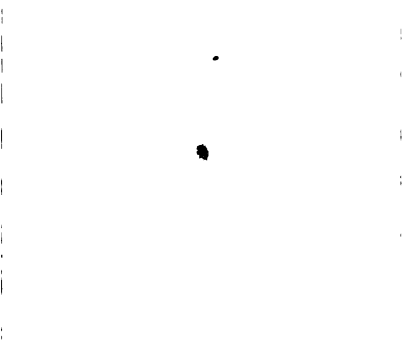


Fig. 56.



Fig. 57.



Fig. 58.



Fig. 59.

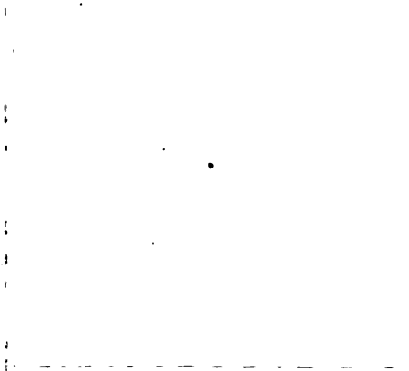


Fig. 60.

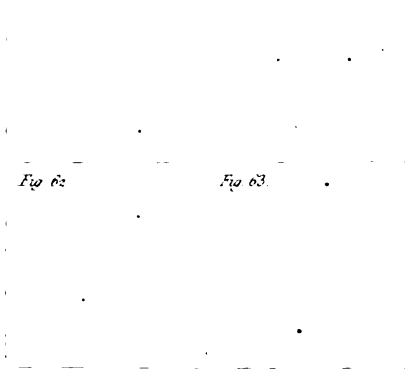


Fig. 61.

Fig. 62.

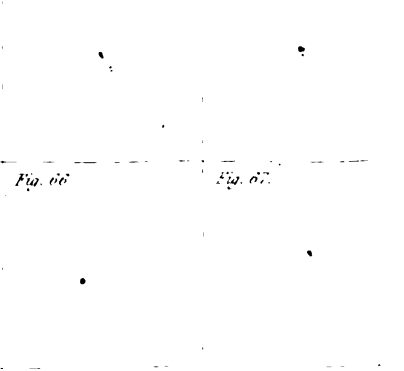


Fig. 63.

Fig. 64.

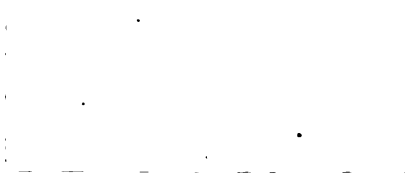


Fig. 65.

Fig. 66.



Fig. 67.

Fig. 68.

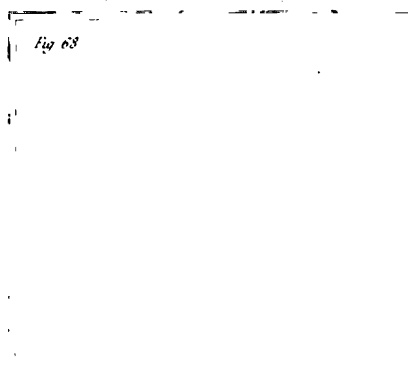


Fig. 69.

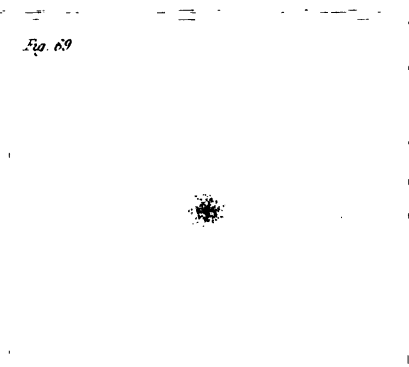


Fig. 70.

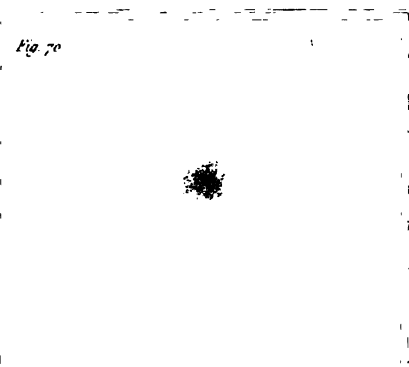


Fig. 71.

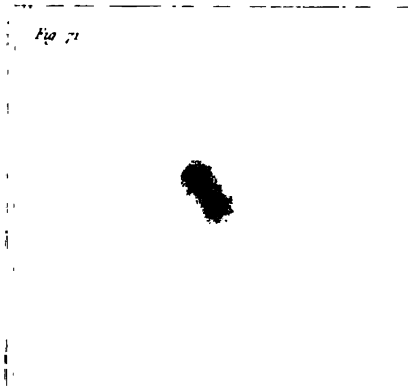


Fig. 72.

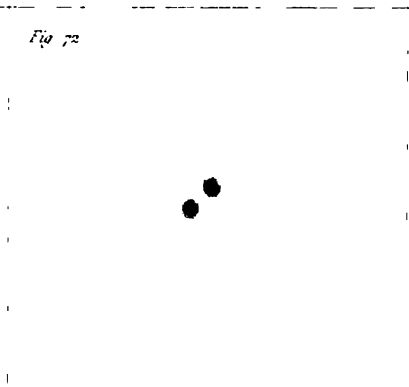


Fig. 73.

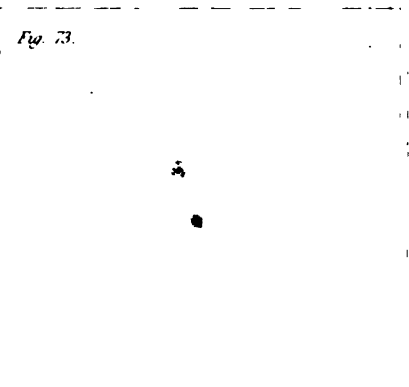


Fig. 74.

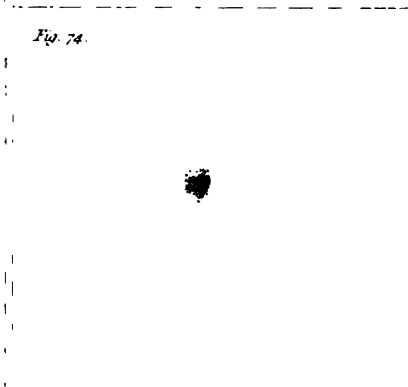


Fig. 75.

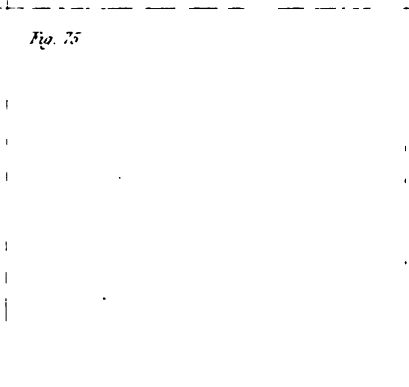


Fig. 76.

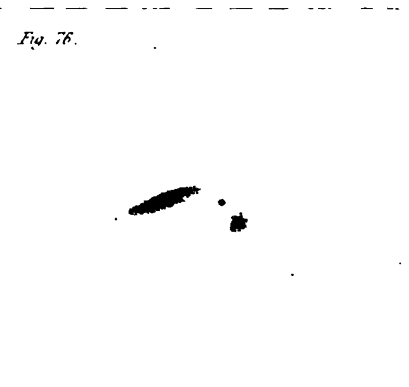


Fig. 77.

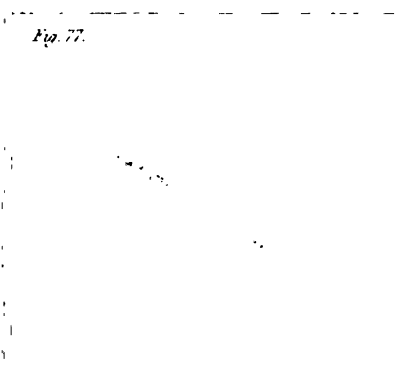


Fig. 78.

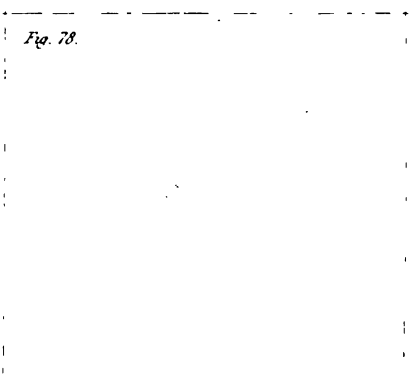


Fig. 79.

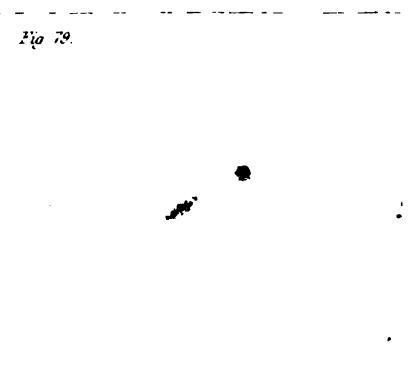


Fig. 80.

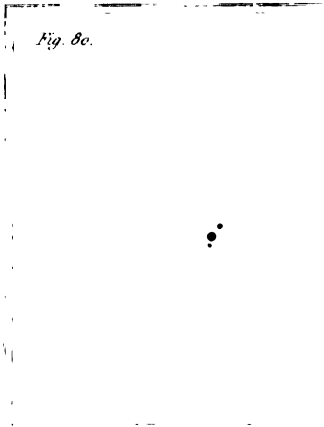


Fig. 81.

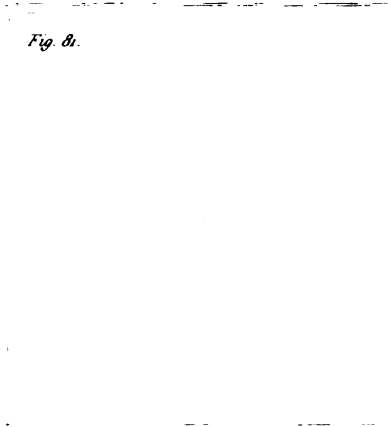


Fig. 82.

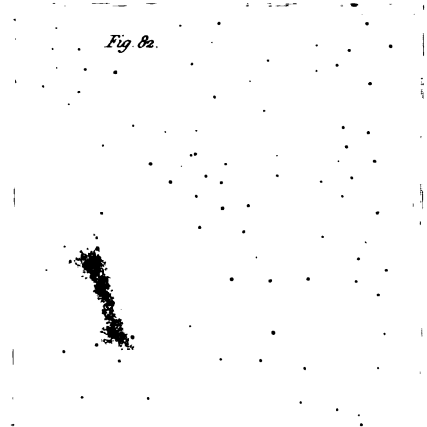


Fig. 83.



Fig. 84.

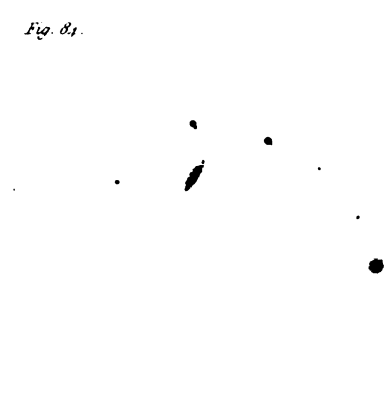


Fig. 85.

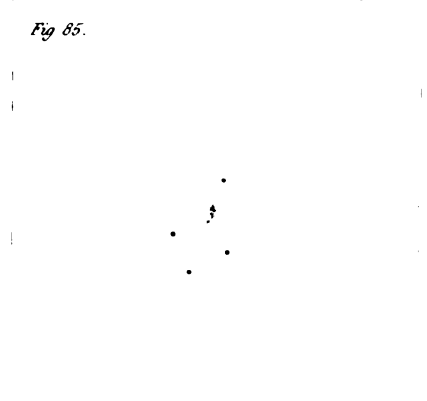


Fig. 86.

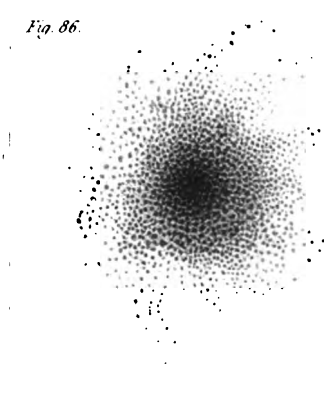


Fig. 87.

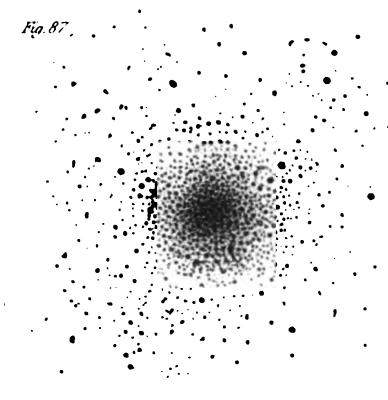


Fig. 88.

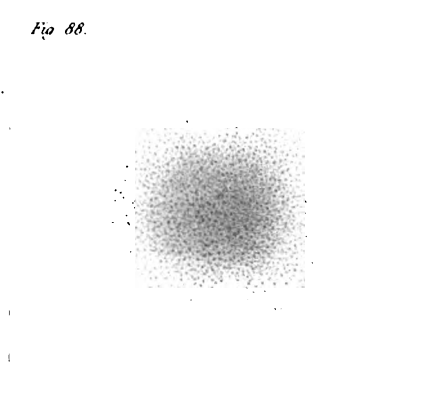


Fig. 89.

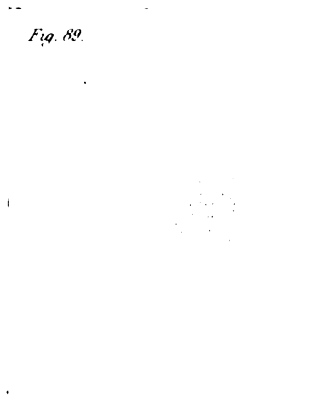


Fig. 90.

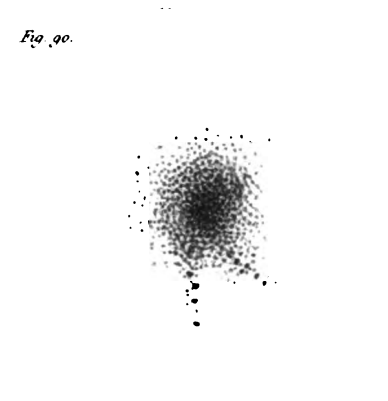
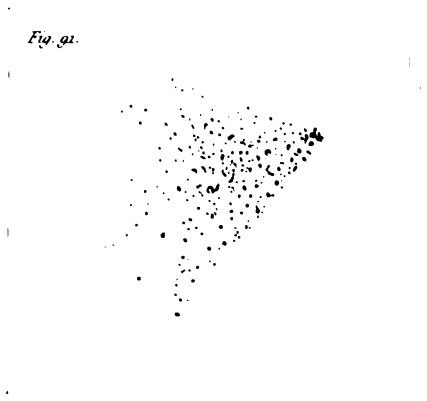


Fig. 91.



See p. 490. Attached and.

See p. 490. Attached and.

List of figured Nebulæ.—Continued.

Plate.	Figure.	Number in Observations.	Synonyms.	R. A.	N. P. D.
XIII.	45	2241	IV. 18	^h 23 ^m 17 ^s 44	48° 24'
	46	2047	IV. 51	19 34 21	104 33
	47	2075	IV. 16	20 14 48	70 26
	48	2072	IV. 13	20 9 33	59 57
	49	355	I. 261	5 20 11	55 54
XIV.	50	1376	I. 43	12 31 11	100 40
	51	859	V. 8	11 11 22	75 28
	52	61	V. 1	0 39 12	116 13
	53	854	M. 65	11 10 2	75 59
	54	875	Nova	11 14 12	76 5
	55	1175	V. 43	12 10 33	41 46
	56	242	I. 156	2 29 46	51 41
	57	1225	I. 210	12 15 6	42 4
	58	151	IV. 42	1 40 4	84 56
	59	1148	I. 109	12 7 15	75 54
	60	2236	II. 600	23 13 58	50 4
	61	536	II. 280	8 45 50	92 25
	62	1499	IV. 30	12 50 57	54 13
	63	2205	I. 55	22 56 26	78 36
	64	399	IV. 2	6 29 53	81 7
	65	537	IV. 66	8 46 33	35 35
	66	1362	III. 602	12 28 28	74 48
	67	1509	I. 143	12 52 2	86 35
XV.	68	1252	V. 29	12 17 22	55 31
	69	1202	{ M. 61 } { I. 139 }	12 13 13	84 35
	70	604	I. 56 & 57	9 22 32	67 45
	71	1146	I. 95	12 7 5	52 44
	72	444	II. 316 & 317 ..	7 14 50	60 11
	73	2197	II. 450. 451 ..	22 51 12	103 43
	74	1408	M. 60. III. 44..	12 35 4	77 31
	75	1414	I. 176. 177	12 35 39	56 54
	76	1397	V. 42. II. 659..	12 33 54	56 30
	77	1905	II. 751. 752 ..	15 0 0	69 48

List of figured Nebulæ.—Continued.

Plate.	Figure.	Number in Observations.	Synonyma.	R. A.	N. P. D.
XV.	78	1358	Nova	^h ^m ^s 12 27 55	77° 49'
	79	936	II. 103.	11 31 24	73 43
XVI.	80	1991	IV. 41	17 52 0	113 1
	81	357	M. 1.	5 24 16	68 7
	82	2093	Nova	20 50 4	60 26
	83	1352	I. 92.	12 27 31	61 6
	84	1466	II. 75 & 74 . . .	12 44 21	77 50
	85	2245	II. 226.	23 19 58	68 31
	86	1968	M. 13	16 35 37	53 13
	87	1916	M. 5.	15 9 56	87 16
	88	2125	M. 2.	21 24 40	91 34
	89	1929	Nova	15 29 9	83 27
	90	2128	M. 30	21 30 42	113 55
	91	415	VI. 2	6 45 18	71 49

Notes on the foregoing List.

Fig. 25. M. 51.—This very singular object is thus described by MESSIER:—"Nébuleuse sans étoiles." "On ne peut la voir que difficilement avec une lunette ordinaire de $3\frac{1}{2}$ pieds." "Elle est double, ayant chacune un centre brillant éloigné l'un de l'autre de $4' 35''$. Les deux atmosphères se touchent." By this description it is evident that the peculiar phenomena of the nebulous ring which encircles the central nucleus had escaped his observation, as might have been expected from the inferior light of his telescopes. My Father describes it in his observations of MESSIER's nebulæ (which are not included in his catalogues,) as a bright round nebula, surrounded by a halo or glory at a distance from it, and accompanied with a companion; but I do not find that the partial subdivision of the ring into two branches throughout its south following limb was noticed by him. This is, however, one of its most remarkable and interesting features. Supposing it to consist of stars, the appearance it would present to a spectator placed on a planet attendant on one of them ex-centrally situated towards the north preceding quarter of the central mass,

would be exactly similar to that of our Milky Way, traversing in a manner precisely analogous the firmament of large stars, into which the central cluster would be seen projected, and (owing to its greater distance) appearing, like it, to consist of stars much smaller than those in other parts of the heavens. Can it, then, be that we have here a brother-system bearing a real physical resemblance and strong analogy of structure to our own? Were it not for the subdivision of the ring, the most obvious analogy would be that of the system of Saturn, and the ideas of LAPLACE respecting the formation of that system would be powerfully recalled by this object. But it is evident that all idea of symmetry caused by rotation on an axis must be relinquished, when we consider that the elliptic form of the inner subdivided portion indicates with extreme probability an elevation of that portion above the plane of the rest, so that the real form must be that of a ring split through half its circumference, and having the split portions set asunder at an angle of about 45° each to the plane of the other.

Fig. 26. MESS. 27.—Described by MESSIER thus: “Nébuleuse sans étoile.” “On la voit bien avec une lunette ordinaire de $3\frac{1}{2}$ pieds: elle paraît sous une forme ovale et ne contient aucune étoile.” In my Father’s observations the true form (like that of a double-headed shot or dumb-bell,) was of course distinctly perceived, and the small stars it contains are noticed, and taken as an indication of its resolvability. I incline, however, to the opinion of their being accidental stars (of which multitudes exist in the surrounding region). But here, as in the former object, the feature which gives a peculiar interest to the whole nebula, and alters entirely the light in which its physical constitution must be considered, has been hitherto overlooked,—I mean the faint nebulosity which fills in the lateral concavities of the body, and converts them in fact into protuberances, so as to render the general outline of the whole nebula, a regular ellipse, having for its *shorter* axis the common axis of the two bright masses of which the body consists, that is to say, the *longer* axis of the oval form, under which it was imperfectly seen by MESSIER. To this axis the complete figure is symmetrical, and if we are disposed to regard it as a mass in rotation, it is about this axis that we must suppose it to revolve. In that case its real form must be that of an oblate spheroid; and as it does not follow that the brightest portions must of necessity be the densest, this supposition would

not be incompatible with dynamical laws, at least, supposing its parts to be capable of exerting pressure on one another. But if it consist of discrete stars, this cannot be admitted, and we must have recourse then to other suppositions to account for the maintenance of its form.

Fig. 27. MESS. 64.—The dark semi-elliptic vacancy (indicated by an unshaded or bright portion in the figure,) which partially surrounds the condensed and bright nucleus of this nebula, is of course unnoticed by MESSIER. It was however seen by my Father, and shown by him to the late Sir CHARLES BLAGDEN, who likened it to the appearance of a *black eye*, an odd, but not inapt comparison. The nucleus is somewhat elongated, and I have a strong suspicion that it may be a close double star, or extremely condensed double nebula.

Fig. 28. V. 19.—An extraordinary object. Perhaps the representation in the figure is too nicely symmetrical, as it certainly is too sharply defined and distinct. It is of the last degree of faintness, and may very well be unperceived, though full in the field of view. There can hardly be a doubt of its being a thin flat ring, of enormous dimensions, seen very obliquely.

Fig. 29. MESS. 57.—The annular nebula in Lyra. It is ill represented. The edges exhibit a curdled and confused appearance, like stars out of focus. The interior is far from absolutely dark. It is filled with a feeble but very evident nebulous light, which I do not remember to have seen noticed by former observers. Comparing figures 25, 27, 28, 29 and 48, it will appear that the annular form, or an approach to it, is one of those which nebulae affect, and taken in connexion with the ring of Saturn and the Milky Way, may lead us to conceive that some kind of analogy, however obscure, may subsist in all those cases.

Fig. 33.—The engraving represents this very strange nebula much too intense. It is an extremely faint object. The large double star is ϵ Cygni.

Fig. 35. MESS. 17.—The figure of this nebula is nearly that of a Greek capital omega Ω , somewhat distorted and very unequally bright. It is remarkable that this is the form usually attributed to the great nebula in Orion, though in that nebula I confess I can discern no resemblance whatever to the Greek letter. MESSIER perceived only the bright preceding branch of the nebula now in question, without any of the attached convolutions which were

first noticed by my Father. The chief peculiarities which I have observed in it are, 1st, the resolvable knot in the following portion of the bright branch, which is in a considerable degree insulated from the surrounding nebula; strongly suggesting the idea of an absorption of the nebulous matter; and 2ndly, the much feebler and smaller knot at the north preceding end of the same branch, where the nebula makes a sudden bend at an acute angle. With a view to a more exact representation of this curious nebula, I have at different times taken micrometrical measures of the relative places of the stars in and near it, by which, when laid down as in a chart, its limits may be traced and identified, as I hope soon to have better opportunity to do than its low situation in this latitude will permit.

Fig. 37. V. 24, and Fig. 50. I. 43.—The strong suspicion of a parallel appendage to the latter of these, is almost converted into certainty by its undoubted existence in V. 24, in which it was seen by two other observers as well as by myself. But what are we to make of such an appendage? Must we consider it as an extreme exaggeration of the case of M. 64 (fig. 27), in which the vacancy is extended up to almost the very extremities of the elliptic outline,—in which case the nebula would come to be regarded as a flat annulus seen at a great obliquity, and having very unequal breadths and densities in its two opposite semicircles? Or must we admit the appendage to be a separate and distinct nebula, dependent, by some unknown physical relation, on its brighter neighbour?

Fig. 43.—This remarkable object, as my Father rightly observes, appears to constitute a connecting link between the planetary nebulæ and nebulous stars. It differs from the latter class of objects in respect of the intensity and comparatively sharp termination of the surrounding light; and no less from the former, in that of its stellar centre. With regard to nebulous stars generally, I ought to mention that it has frequently occurred to me to notice a peculiar state of the atmosphere in which all large stars (above the 7th magnitude) have appeared surrounded with photospheres of 2' or 3' or more in diameter, precisely resembling that about some of the finer specimens of nebulous stars. The state of the air alluded to, is not that in which fog, or any degree of haziness, or thin strata of cloud are perceptible to the sight. These produce no such appearance. Stars are seen through fog, cloud, or ordinary haze, pre-

cisely as if there were no such intervening medium ; only less bright. The photospheres in question are often seen when the sky seems quite pure and clear. They do not arise from dew on the glasses, as is proved by wiping them ; nor in the eye itself, for they do not vanish when the star is made to *blink* behind one of the thick wires of the eye-piece ; nor in scabrous polish of the mirror, for they are not permanent. They come on suddenly ; seldom last very long, and disappear as unexpectedly as they come. When first this phenomenon presented itself, a considerable star which appeared so surrounded was at once set down as a superb nebulous star, and it was not until another and another entered the field similarly affected, that any doubt arose. As regards the true cause of this phenomenon, that it is atmospheric I have no doubt, and perhaps it must be looked for in some highly rarified material, disseminated in cloud-like, though invisible, masses, in the very highest regions of our atmosphere,—the same possibly which, when ignited by the passage of electric currents, gives rise to many if not all the phenomena of the aurora borealis. Be that as it may, the fact that an appearance, exactly resembling that of a nebulous star, may originate in a non-luminous medium, interposed between the eye and the star, serves to render it not improbable that such matter may exist, disseminated through the ether itself in determinate localities, and may render some stars which shine through it nebulous, which have no real nebulous atmospheres about them. The frequency of nebulous stars in the constellation of Orion seems to afford some support to this idea, though I am far from contending that there are no stars really nebulous. Of such the object immediately under consideration, indeed, must be regarded as an undoubted instance.

Figs. 44 47.—Planetary nebulæ. The point to which I should here draw attention is the frequent and close proximity to these objects, of minute stars, which suggest the idea of accompanying satellites. Such they may possibly be. The enormous magnitude of these bodies, and consequent probable mass (if they be not hollow shells), may give them a gravitating energy, which, however rare we may conceive them to be, may yet be capable of retaining in orbits, three or four times their own diameter, and in periods of great length, small bodies of a stellar character. In this point of view a continued series of the angles of position of their companions, micrometrically measured with

3701

due care, would be interesting; and I regret not having sufficiently attended to this in my observations, the few measures given, being hurried, imperfect and discordant.

Plate XIV. Figs. 50 67.—*Long nebulae*. The general form of elongated nebulae is elliptic, and their condensation towards the centre is almost invariably such as would arise from the superposition of luminous elliptic strata, increasing in density towards the centre. In many cases (as in fig. 53,) this increase of density is obviously attended with a diminution of ellipticity, or a nearer approach to the globular form in the central than in the exterior strata. It is probably owing to this, that extended nebulae seen in dull or hazy states of the sky are often described as *round*, the fainter and more elliptic envelopes being obliterated, and only the more globular nuclei perceived. The great extension of some nebulae into long lenticular rays, and the existence of every intermediate degree of ellipticity up to the exact circular form, with the various degrees of rapidity of central condensation, from a barely perceptible increase of density to a seemingly solid nucleus, are all accounted for by supposing the general constitution of these nebulae to be that of oblate spheroidal masses of every degree of flatness from the sphere to the disc, and of every variety in respect of the law of their density and ellipticity towards the centre. It would be incorrect, however, to draw from this any inference as to the identity of the forces which maintain them in this form with those which determine the oblate spheroidal form of a revolving fluid mass under the dominion of the law of gravitation, and subject to compression by the superincumbent matter. If a nebula be nothing more than a cluster of discrete stars, (as we have every reason to believe, at least in the generality of cases,) no pressure can be propagated through it; and its equilibrium, or, to speak more correctly, the permanence of its form, must be maintained in a way totally different. In a system so constituted, no general rotation of the whole, as a mass, can be supposed. It must rather be conceived as a *quiescent form*, comprising within its limits an indefinite multitude of individual constituents, which, for aught we can tell, may be moving one among the other, each animated by its own inherent projectile force, and deflected into an orbit more or less complicated, by the influence of that law of internal gravitation which may result from the compounded attractions of all its parts. I have

shown elsewhere* how a quiescent spherical form may subsist as the bounding outline of an immense number of equal stars uniformly distributed through its extent, each of which individually attracts all the others with a force inversely as the square of the distance, and whose united attractions compose an internal force on each, directly proportional to the distance from the centre of the sphere. In such a state of things, each star might describe an ellipse in any plane, and in any direction in that plane about the common centre, without the possibility of collision; but the sphere, regarded as a whole, would have no rotation about any axis. If the form be not spherical, and the distribution of the stars not homogeneous, the dynamical relations become too complicated to be distinctly apprehended, yet we may still conceive that something of an analogous result may subsist, and that both the external form and the internal density may be maintained (at least under certain conditions,) for the mass as a quiescent whole, while all its elements are in a state of unceasing transfer and interchange.

Plate XV. Figs. 68 . . . 79.—*Double nebulae*. All the varieties of double stars, as to distance, position and relative brightness, have their counterparts in double nebulae; besides which, the varieties of form and gradation of light in the latter afford room for combinations peculiar to this class of objects. The series of figures expressed in this Plate exhibits a considerable number of these combinations; and it will, I think, be found impossible, on casting our eye over its contents, and referring mentally to the great number of similar objects scattered through the heavens, to refuse our assent to the idea of a more intimate physical relation between the individuals of a double nebula than that of mere casual juxtaposition. The argument drawn from the comparative rarity of the objects in proportion to the whole extent of the heavens, so cogent in the case of the double stars, is infinitely more so in that of the double nebulae. Nebulae, for example, so large and faint, and so little condensed towards the centre as those of V. 29, (fig. 68,) are extremely rare, even single, so that the improbability of two such, casually occurring, so near together as to mix their nebulosities, is extreme. It will therefore become a very interesting subject of future inquiry, whether any traces of orbital motion (indicated by a progressive change in their angles of position with respect to the meri-

* Cabinet Cyclopædia, ASTRONOMY, last page.

dian,) can be detected in these combinations. The micrometrical measures of many of them which occur in the foregoing observations, though neither so numerous nor so accurate as might be wished, will at least serve as terms of rough comparison, sufficient at least for the detection of rapid rotations.

Plate XVI. Figs. 80, 82, 83, 84, 85 represent nebulæ which offer some remarkable peculiarity of situation with respect to stars. Of these the most singular are IV, 41, (fig. 80,) and that of fig. 82. The latter, however, is very imperfectly expressed in the drawing. Indeed it would be excessively difficult to execute a drawing of such an object with any pretensions to correctness. In this, general resemblance and character only has been aimed at, enough to express the peculiar feature of the object, which is a network or tracery of nebulæ following the lines of a similar network of stars. It is an extremely faint and difficult object, and only once observed; but I do not think it possible I could have been deceived as to the reality of the phenomenon, especially since the brighter parts of the nebula are stated in the observation to have been distinctly seen.

Figs. 81, 86, 87, 88, 89, 90, 91 are clusters of stars, beginning with a barely resolvable one, (M. 1. fig. 81,) and ascending by successive degrees,—figs. 89, 88, 87,—to M. 13, fig. 86, which is one of the most magnificent assemblages of stars the heavens contain. They are instructive, exhibiting, as they do, an analysis of the intimate structure of nebulæ, on which depend many of the peculiarities of their appearance when no stars can be actually discerned in them, such as, for example, that peculiar character to which, when it has occurred, the epithet “hairy” or “filamentous” has been attached in the descriptions, and which is well illustrated by the figure (fig. 86) of MESSIER’s 13th, and by the description of the 53rd of the *Connaissance des Temps* (No. 1558 in the above observations,) as set down in sweep 63; the border, instead of melting away insensibly, having a ragged or fibrous appearance. Again, fig. 90, if removed far enough to lose the stars, would be described, doubtless, as irregularly round or unsymmetrical, if not as having a bifid or forked tail: and fig. 91 (VI. 2,) would, under similar circumstances of removal, appear as a fan-shaped nebula with a bright point like a star at the vertex, such as is represented in figs. 65, 66, 67, 68.

Before terminating this Appendix, it should be explained what is meant by

the references, so frequent in the observations, to a "working list." It has been my invariable practice to prepare before each night's sweep a list, in order of R. A. with approximate polar distances, of the principal objects occurring within the zone intended to be embraced in the sweep, and about 5' or 10' above and below it. It is needless to mention that the nebulae of these lists were mostly those of my Father's sweeps,—not, however, as taken merely from his printed catalogue, in which only references of their places to the nearest large stars are stated, but as reduced and digested (with great patience and care) into a regular catalogue in zones, by my aunt, Miss CAROLINE HERSCHEL. This valuable MS., which performs the same office with regard to my Father's sweeps, as far as concerns the places of the nebulae, as the present digested and reduced series of observations does to my own, has therefore been, in point of fact, the groundwork of my whole proceedings, and I should be not only ungrateful, but in a high degree unjust, were I to omit in this place acknowledging the advantage I have derived from its use.

At the commencement of my sweeps, I contented myself, however, with a bare notice of the chief expected nebulae, but finding that owing to the interest excited by these objects, the zero stars were too much neglected, and smaller nebulae missed, these came to be inserted at convenient intervals. Subsequently, too, the double stars of STRUVE's catalogue began to be entered on the lists; and at length, experience having shown me that no trouble bestowed on the construction of an ample and exact "working list" could be considered ill bestowed, I threw aside all the earlier lists of this sort, and dividing the heavens into zones of polar distance, of 3° in breadth from 0° to 120°, proceeded to construct a series of lists or approximate catalogues in order of R. A. for 1830, in which should be comprised the following objects:

- 1st. All my Father's nebulae and clusters.
- 2nd. MESSIER's ditto.
- 3rd. All other nebulae and clusters of which any hints could anywhere be found, including new ones from my own sweeps, inserted from time to time.
- 4th. All the double stars of STRUVE's greater catalogue.
- 5th. All other remarkable double stars of which any record could be found, either in my own sweeps or elsewhere.
- 6th. A series of zero stars, chosen so as to interfere as little as possible with

the other objects, and selected from the catalogue of the Astronomical Society; or where none fit for the purpose could be found there, from PIAZZI's; or failing that, from other authorities.

The construction of the "working lists" on this extended scale, has formed a very large part of the regular work of my sweeps; but so far from regretting the trouble they have cost, or regarding it as waste labour, I can only lament having deferred their full execution till impressed by the experience of much more, and far more valuable observing time lost, with a sense of their importance.

One consequence of the construction of the working lists has been the gradual accumulation of a pretty extensive catalogue of missing nebulae;—perhaps it would be more correct to say, nebulae not found when looked for. The fainter nebulae are so easily overlooked, even when in the field of view, and are altogether such very delicate objects, that it is the most difficult thing in the world to prove the negative proposition as to their existence. Many such cases, too, must have originated in mistaken entries on the list, some doubtless in mistakes in the observations from which those lists were constructed, and some from actually looking in the wrong places by mistaken settings of the telescope. Aware of all these possibilities, I have thought it best to suppress this list for the present, having had no time to go into an examination of the subject. Indeed I doubt whether it would be worth while to do so. There seems very little probability that a real nebula should have disappeared from the heavens; and though some few telescopic comets may have been noticed in my Father's sweeps, and set down as nebulae, the chances are almost infinite against any such observation, if ascertained, proving of use as a datum for improving the elements of any recorded comet.

XX. *Experimental Researches in Electricity.—Fourth Series.* By MICHAEL FARADAY, D.C.L. F.R.S. M.R.I. &c. &c. &c., *Fullerian Prof. Chem. Royal Institution, Corr. Mem. Royal Acad. of Sciences, Paris, Petersburg, Florence, Copenhagen, Berlin, &c. &c.*

Received April 24,—Read May 23, 1833.

§ 9. *On a new Law of Electric Conduction.* § 10. *On Conducting Power generally.*

§ 9. *On a new Law of Electric Conduction.*

380. **I**T was during the progress of investigations relating to electro-chemical decomposition, which I still have to submit to the Royal Society, that I encountered effects due to a very general law of electric conduction not hitherto recognised; and though they prevented me from obtaining the condition I sought for, they afforded abundant compensation for the momentary disappointment, by the new and important interest which they gave to an extensive part of electrical science.

381. I was working with ice, and the solids resulting from the freezing of solutions, arranged either as barriers across a substance to be decomposed, or as the actual poles of a voltaic battery, that I might trace and catch certain elements in their transit, when I was suddenly stopped in my progress by finding that ice was a non-conductor of electricity; and that as soon as a thin film of it was interposed, in the circuit of a very powerful voltaic battery, the transmission of electricity was prevented, and all decomposition ceased.

382. At first the experiments were made with ordinary ice, during the cold freezing weather of the latter end of January (1833); but the results were fallacious, from the imperfection of the arrangements, and the following more unexceptionable form of experiment was adopted.

383. Tin vessels were formed, open at one extremity, five inches deep, one

inch and a quarter wide in one direction, and of different widths, from three eighths to five eighths of an inch, in the other. Into these were fixed by corks, plates of platina, so that the latter should not touch the tin cases; and copper wires having previously been soldered to the plates, these were easily connected, when required, with a voltaic pile. Then distilled water, previously boiled for three hours, was poured into the vessels, and frozen by a mixture of salt and snow, so that pure transparent solid ice intervened between the platina and tin; and finally these metals were connected with the opposite extremities of the voltaic apparatus, a galvanometer being at the same time included in the circuit.

384. In the first experiment, the platina pole was three inches and a half long, and seven eighths of an inch wide; it was wholly immersed in the water or ice, and as the vessel was four eighths of an inch in width, the average thickness of the intervening ice was only a quarter of an inch, and the surface of contact with it at both poles equal to nearly fourteen square inches. After the water was frozen, the vessel was still retained in the frigorific mixture, whilst contact between the tin and platina respectively was made with the extremities of a well charged voltaic battery, consisting of twenty pairs of four-inch plates, each with double coppers. Not the slightest deflection of the galvanometer needle occurred.

385. On taking the frozen arrangement out of the cold mixture, and applying warmth to the bottom of the tin case, so as to melt part of the ice, the connexion with the battery being retained, the needle did not at first move; and it was only when the thawing process had extended so far as to liquefy part of the ice touching the platina pole, that conduction took place; but then it occurred effectually, and the galvanometer needle was permanently deflected nearly 70° .

386. In another experiment, a platina spatula, five inches in length and seven eighths of an inch in width, had four inches fixed in the ice, and the latter was only three sixteenths of an inch thick between one metal and the other; yet this arrangement insulated as perfectly as the former.

387. Upon pouring a little water in at the top of this vessel on the ice, still the arrangement did not conduct; yet fluid water was evidently there. This effect was found to be dependent on the cold metals having frozen the

water where they touched it, and thus insulating the fluid part; and it well illustrates the nonconducting power of ice, by showing how thin a film could prevent the transmission of the battery current. Upon thawing parts of this thin film, where it touched *both* metals, conduction occurred.

388. Upon warming the tin and removing the piece of ice, it was found that from a cork having slipped, one of the edges of the platina had been all but in contact with the inner surface of the tin vessel; yet, notwithstanding the extreme thinness of the interfering ice in this place, no sensible portion of electricity had passed.

389. These experiments were repeated many times with the same results. At last a battery of fifteen troughs, or one hundred and fifty pairs of four-inch plates, powerfully charged, was used; yet even here no sensible quantity of electricity passed the thin barrier of ice.

390. It seemed at first as if occasional departures from these effects occurred; but they could always be traced to some interfering circumstances. The water should in every instance be well frozen; for though it is not necessary that the ice should reach from pole to pole, since a barrier of it about one pole would be quite sufficient to prevent conduction, yet, if part remain fluid, the mere necessary exposure of the apparatus to the air, or the approximation of the hands, is sufficient to produce, at the upper surface of the water and ice, a film of fluid extending from the platina to the tin; and then conduction occurs. Again, if corks are used to block the platina in its place, and these corks being immersed, are damp or wet within, it is needful that the cold be sufficiently well applied to freeze the water within them, or else when the surfaces of their contact with the tin become slightly warm by handling, that part will conduct, and the interior being ready to conduct also, the current will pass. The water should be pure, not only that unembarrassed results may be obtained, but also that, as the freezing proceeds, a minute portion of concentrated saline solution may not be formed, which remaining fluid, and being interposed in the ice, or passing into cracks from contraction, may exhibit conducting powers independent of the ice itself.

391. On one occasion I was surprised to find that after thawing much of the ice the conducting power had not been restored; but I found that a cork

which held the wire just where it joined the platina, dipped so far into the ice, that with the ice itself it protected the platina from contact with the melted part long after that contact was expected.

392. This insulation exhibited by ice is not effective with electricity of exalted intensity. On touching a diverged gold-leaf electrometer with a wire connected with the platina, whilst the tin case was touched by the hand or another wire, the electrometer was instantly discharged (419.).

393. But though electricity of an intensity so low that it cannot diverge the electrometer, can still pass (though in very limited quantities (419.)) through ice; the comparative relation of water and ice to the electricity of the voltaic apparatus is not less extraordinary on that account, or less important in its consequences.

394. As it did not seem likely that this law of the assumption of conducting power during liquefaction, and loss of it during congelation, should be peculiar to water, I immediately proceeded to ascertain its influence in other cases, and found it to be very general. For this purpose bodies were chosen which, being solid at common temperatures, were fusible; and of such composition as, for other reasons connected with electro-chemical action, led to the conclusion that they would be able to replace water. A voltaic battery of two troughs, or twenty pairs of four-inch plates (384.), was used as the source of electricity, and a galvanometer introduced into the circuit to indicate the presence or absence of a current.

395. On fusing a little chloride of lead by a spirit-lamp on a fragment of a Florence flask, and introducing two platina wires connected with the poles of the battery, there was instantly powerful action, the galvanometer was most violently affected, and the chloride rapidly decomposed. On removing the lamp, the instant the chloride solidified all current and consequent effects ceased, though the platina wires remained inclosed in the chloride not more than the one-sixteenth of an inch from each other. On renewing the heat, as soon as the fusion had proceeded far enough to allow liquid matter to connect the poles, the electrical current instantly passed.

396. On fusing the chloride, with one wire introduced, and then touching the liquid with the other, the latter (being cold,) caused a little knob to con-

crete on its extremity, and no current passed; and it was only when the wire became so hot as to be able to allow contact with the liquid matter, that conduction took place; and then it was very powerful.

397. When chloride of silver and chlorate of potassa were experimented with, in a similar manner, exactly the same results occurred.

398. Whenever the current passed in these cases, there was decomposition of the substances; but the electro-chemical part of this subject I purpose connecting with more general views in a future paper*.

399. Other substances, which could not be melted on glass, were fused by the lamp and blowpipe on platina connected with one pole of the battery, and then a wire, connected with the other, dipped into them. In this way mixed carbonates of potash and soda, chloride of sodium, sulphate of soda, protoxide of lead, &c. &c. &c., exhibited exactly the same phenomena as those already described. Whilst liquid, they conducted and were decomposed; whilst solid, though very hot, they insulated the battery current even when four troughs were used.

400. Occasionally the substances were contained in small bent tubes of green glass, and when fused, the platina poles introduced, one on each side. In such cases the same general results as those already described were procured; but a further advantage was obtained, namely, that whilst the substance was conducting and decomposing, the final arrangement of the elements could be observed. Thus, iodides of potassium and lead gave iodine at the positive pole, and potassium or lead at the negative pole. Chlorides of iodine and silver gave chlorine at the positive, and metals at the negative pole. Nitre and chlorate of potassa gave oxygen, &c., at the positive, and alkali, or even potassium, at the negative pole.



401. A fourth arrangement was used for substances requiring very high temperature for their fusion. A platina wire was connected with one pole of

* In 1801, Sir H. DAVY knew that "dry nitre, caustic potash, and soda are conductors of galvanism when rendered fluid by a high degree of heat," (*Journals of the Royal Institution*, 1802, p. 53,) but was not aware of the general law which I have been engaged in developing. It is remarkable, that eleven years after that, he should say, "There are no fluids known except such as contain water, which are capable of being made the medium of connexion between the metal or metals of the voltaic apparatus." *Elements of Chemical Philosophy*, p. 169.

the battery; its extremity bent into a small ring, in the manner described by **BERZELIUS**, for blowpipe experiments; a little of the salt, glass, or other substance, was melted on this ring by the ordinary blowpipe, or even in some cases by the oxy-hydrogen blowpipe, and when the drop, retained in its place by the ring, was thoroughly hot and fluid, a platina wire from the opposite pole of the battery was made to touch it, and the effects observed.

402. The following are various substances taken from very different classes, chemically considered, which are subject to this law. The list might, no doubt, be enormously extended; but I have not had time to do more than confirm the law by a sufficient number of instances.

First, *water*.

Amongst *oxides*;—potassa, protoxide of lead, glass of antimony, protoxide of antimony, oxide of bismuth.

Chlorides of potassium, sodium, barium, strontium, calcium, magnesium, manganese, zinc, copper (proto-), lead, tin (proto-), antimony, silver.

Iodides of potassium, zinc and lead, protiodide of tin, periodide of mercury; fluoride of potassium; cyanide of potassium; sulpho-cyanide of potassium.

Salts. Chlorate of potassa; nitrates of potassa, soda, baryta, strontia, lead, copper, and silver; sulphates of soda and lead, proto-sulphate of mercury; phosphates of potassa, soda, lead, copper, phosphoric glass or acid phosphate of lime; carbonates of potassa and soda, mingled and separate; borax, borate of lead, per-borate of tin; chromate of potassa, bi-chromate of potassa, chromate of lead; acetate of potassa.

Sulphurets. Sulphuret of antimony, sulphuret of potassium made by reducing sulphate of potassa by hydrogen; ordinary sulphuret of potassa.

Silicated potassa; chameleon mineral.

403. It is highly interesting in the instances of those substances which soften before they liquefy, to observe at what period the conducting power is acquired, and to what degree it is exalted by perfect fluidity. Thus, with the borate of lead, when heated by the lamp upon glass, it becomes as soft as treacle, but it did not conduct, and it was only when urged by the blowpipe and brought to a fair red heat, that it conducted. When rendered quite liquid, it conducted with extreme facility.

404. I do not mean to deny that part of the increased conducting power in

these cases of softening was probably due to the elevation of temperature (432. 445.); but I have no doubt that by far the greater part was due to the influence of the general law already demonstrated, and which in these instances came gradually, instead of suddenly, into operation.

405. The following are bodies which acquired no conducting power upon assuming the liquid state :—

Sulphur, phosphorus; iodide of sulphur, per-iodide of tin; orpiment, realgar; glacial acetic acid, mixed margaric and oleic acids, artificial camphor; caffeine, sugar, adipocire, stearine of cocoa-nut oil, spermaceti, camphor, naphthaline, resin, gum sandarach, shell lac.

406. Perchloride of tin, chloride of arsenic, and the hydrated chloride of arsenic, being liquids, had no sensible conducting power indicated by the galvanometer, nor were they decomposed.

407. Some of the above substances are sufficiently remarkable as exceptions to the general law governing the former cases. These are orpiment, realgar, acetic acid, artificial camphor, per-iodide of tin, and the chlorides of tin and arsenic. I shall have occasion to refer to these cases in the paper on Electrochemical Decomposition.

408. Boracic acid was raised to the highest possible temperature by an oxy-hydrogen flame (401.), yet it gained no conducting powers sufficient to affect the galvanometer, and underwent no apparent voltaic decomposition. It seemed to be quite as bad a conductor as air. Green bottle-glass, heated in the same manner, did not gain conducting power sensible to the galvanometer. Flint glass, when highly heated, did conduct a little and decompose; and as the proportion of potash or oxide of lead increased in the glass, the effects were more powerful. Those glasses, consisting of boracic acid on the one hand, and oxide of lead or potassa on the other, show the assumption of conducting power upon fusion and the accompanying decomposition very well.

409. I was very anxious to try the general experiment with sulphuric acid, of about specific gravity 1.783, containing that proportion of water which gives it the power of crystallizing at 40° FAHR.; but I found it impossible to obtain it so that I could be sure the whole would congeal even at 0° FAHR. A ten-thousandth part of water, more or less than necessary, would, upon cooling the whole, cause a portion of uncongealable liquid to separate, and that remaining

in the interstices of the solid mass, and moistening the planes of division, would prevent the correct observation of the phenomena due to entire solidification and subsequent liquefaction.

410. With regard to those substances on which conducting power is conferred by liquidity, the degree of power so given is generally very great. Water is that body in which this acquired power is feeblest. In the various oxides, chlorides, salts, &c. &c., it is given in a much higher degree. I have not had time to measure the conducting power in these cases, but it is apparently some hundred times that of pure water. The increased conducting power known to be given to water by the addition of salts, would seem to be in a great degree dependent upon the high conducting power of these bodies when in the liquid state, that state being given them for the time, not by heat but solution in the water.

411. Whether the conducting power of these liquefied bodies is a consequence of their decomposition or not (413.), or whether the two actions of conduction and decomposition are essentially connected or not, would introduce no difference affecting the probable accuracy of the preceding statement.

412. This general assumption of conducting power by bodies as soon as they pass from the solid to the liquid state, offers a new and extraordinary character; the existence of which, as far as I know, has not before been suspected; and it seems importantly connected with some properties and relations of the particles of matter which I may now briefly point out.

413. In almost all the instances, as yet observed, which are governed by this law, the substances experimented with have been those which were not only compound bodies, but such as contain elements known to arrange themselves at the opposite poles, and also such as could be decomposed by the electrical current. When conduction took place, decomposition occurred; when decomposition ceased, conduction ceased also; and it becomes a fair and an important question, Whether the conduction itself may not, wherever the law holds good, be a consequence not merely of the capability, but of the act of decomposition? And that question may be accompanied by another, namely, Whether solidification does not prevent conduction, merely by chaining the particles to their places, under the influence of aggregation, and preventing their final separation in the manner necessary for decomposition?

414. But, on the other hand, there is one substance (and others may occur), the per-iodide of mercury, which, being experimented with like the others (400.), was found to insulate when solid, and to acquire conducting power when fluid; yet it did not seem to undergo decomposition in the latter case.

415. Again, there are many substances which contain elements such as would be expected to arrange themselves at the opposite poles of the pile, and therefore in that respect fitted for decomposition, which yet do not conduct. Amongst these are the iodide of sulphur, per-iodide of zinc, per-chloride of tin, chloride of arsenic, hydrated chloride of arsenic, acetic acid, orpiment, realgar, artificial camphor, &c.; and from these it might perhaps be assumed that decomposition is dependent upon conducting power, and not the latter upon the former. The true relation, however, of conduction and decomposition in those bodies governed by the general law which it is the object of this paper to establish, can only be satisfactorily made out after a far more extensive series of observations than those I have yet been able to supply.

416. The relation under this law of the conducting power for electricity to that for heat, is very remarkable, and seems to imply a natural dependence of the two. As the solid becomes a fluid, it loses almost entirely the power of conduction for heat, but gains in a high degree that for electricity; but as it reverts back to the solid state, it gains the power of conducting heat, and loses that of conducting electricity. If, therefore, the properties are not incompatible, still they are most strongly contrasted, one being lost as the other is gained. We may hope, perhaps, hereafter to understand the physical reason of this very extraordinary relation of the two conducting powers, both of which appear to be directly connected with the corpuscular condition of the substances concerned.

417. The assumption of conducting power and a decomposable condition by liquefaction, promises new opportunities of and great facilities in voltaic decomposition. Thus, such bodies as the oxides, chlorides, cyanides, sulphocyanides, fluorides, certain vitreous mixtures, &c. &c., may be submitted to the action of the voltaic battery under new circumstances; and indeed I have already been able, with ten pairs of plates, to decompose common salt, chloride of magnesium, borax, &c. &c., and to obtain sodium, magnesium, boron, &c., in their separate states.

§ 10. *On Conducting Power generally.*

418. It is not my intention here to enter into an examination of all the circumstances connected with conducting power, but to record certain facts and observations which have arisen during recent inquiries, as additions to the general stock of knowledge relating to this point of electrical science.

419. I was anxious, in the first place, to obtain some idea of the conducting power of ice and solid salts for electricity of high tension (392.), that a comparison might be made between it and the large accession of the same power gained upon liquefaction. For this purpose the large electrical machine (290.) was brought into excellent action, its conductor connected with a delicate gold-leaf electrometer, and also with the platina inclosed in the ice, whilst the tin case was connected with the discharging train (292.). On working the machine moderately, the gold leaves barely opened; on working it rapidly, they could be opened nearly two inches. In this instance the tin case was five eighths of an inch in width; and as, after the experiment, the platina plate was found very nearly in the middle of the ice, the average thickness of the latter had been five sixteenths of an inch, and the extent of surface of contact with tin and platina fourteen square inches (384.). Yet, under these circumstances, it was but just able to conduct the small quantity of electricity which this machine could evolve (371.), even when of a tension competent to open the leaves two inches; no wonder, therefore, that it could not conduct any sensible portion of the electricity of the troughs (384.), which, though almost infinitely surpassing that of the machine in quantity, had a tension so low as not to be sensible to an electrometer.

420. In another experiment, the tin case was only four eighths of an inch in width, and it was found afterwards that the platina had been not quite one eighth of an inch distant in the ice from one side of the tin vessel. When this was introduced into the course of the electricity from the machine (419.), the gold leaves could be opened, but not more than half an inch; the thinness of the ice favouring the conduction of the electricity, and permitting the same quantity to pass in the same time, though of a lower tension.

421. Fused iodide of potassium was then introduced into the course of the electricity from the machine. There were two pieces, each about a quarter of

an inch in thickness, and exposing a surface on each side equal to about half a square inch; these were placed upon platina plates, one connected with the machine and electrometer (419.), and the other with the discharging train, whilst a fine platina wire connected the two pieces, resting upon them by its two points. On working the electrical machine, it was possible to open the electrometer leaves about two thirds of an inch.

422. As the platina wire touched only by points, the facts show that this salt is a far better conductor than ice; but as the leaves of the electrometer opened, it is also evident with what difficulty conduction, even of the small portion of electricity produced by the machine, is effected by this body in the solid state, when compared to the facility with which enormous quantities at very low tensions are transmitted by it when in the fluid state.

423. In order to confirm these results by others, obtained from the voltaic battery, one of one hundred and fifty plates, four inches square, was well charged: its action was good; the shock from it strong; the discharge would continue from copper to copper through four tenths of an inch of air, and the gold-leaf electrometer before used could be opened nearly a quarter of an inch.

424. The ice vessel used (420.) was half an inch in width. The extent of contact of the ice with the tin and platina being nearly fourteen square inches, it was equivalent to a plate of ice having a surface of seven square inches of perfect contact at each side, and only one fourth of an inch thick. It was retained in a freezing mixture during the experiment.

425. The order of arrangement in the course of the electric current was as follows. The positive pole of the battery was connected by a wire with the platina plate in the ice; the plate was in contact with the ice, the ice with the tin jacket, the jacket with a wire, which communicated with a piece of tin foil, on which rested one end of a bent platina wire (312.), the other or decomposing end being supported on paper moistened with solution of iodide of potassium (316.): the paper was laid flat on a platina spatula connected with the negative end of the battery. All that part of the arrangement between the ice vessel and the decomposing wire point, including both these, was insulated, so that no electricity might pass through the latter which had not traversed the former also.

426. Under these circumstances, it was found that a pale brown spot of iodine

MDCCCXXXIII.

3 x

was slowly formed under the decomposing platina point, thus indicating that ice could conduct a little of the electricity evolved by a voltaic battery charged up to the degree of intensity indicated by the electrometer. But it is quite evident that notwithstanding the enormous quantity of electricity which the battery could furnish, it was, under present circumstances, a very inferior instrument to the ordinary machine; for the latter could send as much through the ice as it could carry, being of a far higher intensity, *i. e.* able to open the electrometer leaves half an inch or more (419. 420.).

427. The decomposing wire and solution of iodide of potassium were then removed, and replaced by a very delicate galvanometer (205.); it was so nearly astatic, that it vibrated to and fro in about sixty-three beats of a watch giving one hundred and fifty beats in a minute. The same feebleness of current as before was still indicated; the galvanometer needle was deflected, but it required to break and make contact three or four times (297.), before the effect was very decided.

428. The galvanometer being removed, two platina plates were connected with the extremities of the wires, and the tongue placed between them, so that the whole charge of the battery, so far as the ice would let it pass, was free to go through the tongue. Whilst standing on the stone floor, there was shock, &c. &c., but when insulated, I could feel no sensation. I think a frog would have been scarcely, if at all, affected.

429. The ice was now removed, and experiments made with other solid bodies, for which purpose they were placed under the end of the decomposing wire instead of the solution of iodide of potassium. For instance, a piece of dry iodide of potassium was placed on the spatula connected with the negative pole of the battery, and the point of the decomposing wire placed upon it, whilst the positive end of the battery communicated with the latter. A brown spot of iodine very slowly appeared, indicating the passage of a little electricity, and agreeing in that respect with the results obtained by the use of the electrical machine (421.). When the galvanometer was introduced into the circuit at the same time with the iodide, it was with difficulty that the action of the current on it could be rendered sensible.

430. A piece of fused common salt being introduced into the circuit was sufficient almost entirely to destroy the action on the galvanometer. Fused

chloride of lead produced the same effect. The conducting power of these bodies, when fluid, is very great (395. 402.).

431. All these effects, produced by using the common machine and the voltaic battery, agree therefore with each other, and with the law laid down in this paper, and also with the opinion I have supported, in the Third Series of these Researches, of the identity of electricity derived from different sources.

432. The effect of heat in increasing the conducting power of many substances, especially for electricity of high tension, is well known. I have lately met with an extraordinary case of this kind, for electricity of low tension, or that of the voltaic pile, and which is in direct contrast with the influence of heat upon metallic bodies, as observed and described by Sir HUMPHRY DAVY*.

433. The substance presenting this effect is sulphuret of silver. It was made by fusing a mixture of precipitated silver and sublimed sulphur, removing the film of silver by a file from the exterior of the fused mass, pulverizing the sulphuret, mingling it with more sulphur, and fusing it again in a green glass tube, so that no air should obtain access during the process. The surface of the sulphuret being again removed by a file or knife, it was considered quite free from uncombined silver.

434. When a piece of this sulphuret, half an inch in thickness, was put between surfaces of platina, terminating the poles of a voltaic battery of twenty pairs of four-inch plates, a galvanometer being also included in the circuit, the needle was slightly deflected, indicating a feeble conducting power. On pressing the platina poles and sulphuret together with the fingers, the conducting power increased as the whole became warm. On applying a lamp under the sulphuret between the poles, the conducting power rose rapidly with the heat, and at last the galvanometer needle jumped into a fixed position, and the sulphuret was found conducting in the manner of a metal. On removing the lamp and allowing the heat to fall, the effects were reversed, the needle at first began to vibrate a little, then gradually left its transverse direction, and at last returned to a position very nearly that which it would take when no current was passing through the galvanometer.

435. Occasionally, when the contact of the sulphuret with the platina poles was good, the battery freshly charged, and the commencing temperature not

* Philosophical Transactions, 1821, p. 431.

too low, the mere current of electricity from the battery was sufficient to raise the temperature of the sulphuret; and then, without any application of extraneous heat, it went on increasing conjointly in temperature and conducting power, until the cooling influence of the air limited the effects. In such cases it was generally necessary to cool the whole purposely, to show the returning series of phenomena.

436. Occasionally, also, the effects would sink of themselves, and could not be renewed until a fresh surface of the sulphuret had been applied to the positive pole. This was in consequence of peculiar results of decomposition, to which I shall have occasion to revert in the section on Electro-chemical Decomposition, and was conveniently avoided by inserting the ends of two pieces of platina wire into the opposite extremities of a portion of sulphuret fused in a glass tube, and placing this arrangement between the poles of the battery.

437. The hot sulphuret of silver conducts sufficiently well to give a bright spark with charcoal, &c. &c., in the manner of a metal.

438. The native grey sulphuret of silver, and the ruby silver ore, both presented the same phenomena. The native malleable sulphuret of silver presented precisely the same appearances as the artificial sulphuret.

439. There is no other body with which I am acquainted, that, like sulphuret of silver, can compare with metals in conducting power for electricity of low tension when hot, but which, unlike them, during cooling, loses in power, whilst they, on the contrary, gain. Probably, however, many others may, when sought for, be found.

440. The proto-sulphuret of iron, the native per-sulphuret of iron, arsenical sulphuret of iron, native yellow sulphuret of copper and iron, grey artificial sulphuret of copper, artificial sulphuret of bismuth, and artificial grey sulphuret of tin, all conduct the voltaic battery current when cold, more or less, some giving sparks like the metals, others not being sufficient for that high effect. They did not seem to conduct better when heated, than before; but I had not time to enter accurately into the investigation of this point. Almost all of them became much heated by the transmission of the current, and present some very interesting phenomena in that respect. The sulphuret of antimony does not conduct sensibly either hot or cold, but is amongst those bodies acquiring conducting power when fused (402.). The sulphuret of silver and

perhaps some others decompose whilst in the solid state; but the phenomena of this decomposition will be reserved for its proper place in the next series of these Researches.

441. Notwithstanding the extreme dissimilarity between sulphuret of silver and gases or vapours, I cannot help suspecting the action of heat upon them to be the same, bringing them all into the same class as conductors of electricity, although with those great differences in degree, which are found to exist under common circumstances. When gases are heated, they increase in conducting power, both for common and voltaic electricity (271.); and it is probable that if we could compress and condense them at the same time, we should still further increase their conducting power. CAGNIARD DE LA TOUR has shown that a substance, for instance water, may be so expanded by heat whilst in the liquid state, or condensed whilst in the vaporous state, that the two states shall coincide at one point, and the transition from one to the other be so gradual that no line of demarcation can be pointed out*; that, in fact, the two states shall become one;—which state presents us at different times with differences in degree as to certain properties and relations; and which differences are, under ordinary circumstances, so great as to be equivalent to two different states.

442. I cannot but suppose at present that at that point where the liquid and the gaseous state coincide, the conducting properties are the same for both; but that they diminish as the expansion of the matter into a rarer form takes place by the removal of the necessary pressure; still, however, retaining, as might be expected, the capability of having what feeble conducting power remains, increased by the action of heat.

443. I venture to give the following summary of the conditions of conduction in bodies, not however without fearing that I may have omitted some important points.

444. All bodies conduct electricity in the same manner from metals to lac and gases, but in very different degrees.

445. Conducting power is in some bodies powerfully increased by heat, and in others diminished, yet without our perceiving any accompanying essential

* *Annales de Chimie*, xxi. pp. 127, 178.

electrical difference, either in the bodies or in the changes occasioned by the electricity conducted.

446. A numerous class of bodies insulating electricity of low intensity when solid, conduct it very freely when fluid, and are then decomposed by it.

447. But there are many fluid bodies which do not sensibly conduct electricity of this low intensity; there are some which conduct it and are not decomposed; nor is fluidity essential to decomposition*.

448. There is but one body yet discovered† which, insulating a voltaic current when solid, and conducting it when fluid, is not decomposed in the latter case (414.).

449. There is no strict electrical distinction of conduction which can, as yet, be drawn between bodies supposed to be elementary, and those known to be compounds.

* See the next series of these Experimental Researches.

† It is just possible that this case may, by more delicate experiment, hereafter disappear.

Royal Institution,
April 15, 1833.

XXI. *Experimental Researches on Atomic Weights.* By EDWARD TURNER, M.D.
*F.R.S. Lond. & Ed., Sec. G.S., Professor of Chemistry in the University of
 London.*

Received April 25,—Read May 16, 1833.

THE present communication may be viewed as the continuation of an Essay on the Composition of the Chloride of Barium, which was honoured with a place in the Philosophical Transactions for the year 1829. In resuming the subject after such a long interval, I feel it right to apologize to the Society for the unfinished state in which that Essay has hitherto been left,—an omission far from voluntary, and entirely due to circumstances not subject to my own controul. In one point of view, however, the delay has been advantageous: it has afforded an opportunity to chemists to verify or correct the results contained in my first Essay, and has enabled me to repeat and extend my researches.

The object which I proposed to myself in commencing the present inquiry, was to re-examine some of those estimates which chemists have occasion to use continually as elements in their calculations, and to confide in as the foundation of their doctrines. With this view I undertook to determine the relative accuracy of the atomic weights which the British and Continental chemists respectively employ; and several circumstances induced me to begin by analysing the chloride of barium. Dr. THOMSON, on whose experiments the British chemists relied, had obtained so many of his results by means of the chloride of barium, that any material error in the constitution of that compound would necessarily vitiate a large part of his table of equivalents; and if, on the other hand, the estimate of Dr. THOMSON proved to be correct, an important error would be chargeable against BERZELIUS, whose numbers are very generally adopted on the Continent. The result of the inquiry is now well known: the source of fallacy, pointed out in my first communication, has been admitted by Dr. THOMSON in the new edition of his *System of Chemistry**, and he has accordingly changed the equivalent of barium from 70 to 68.

* Seventh Edition, vol. i. p. 427.

The inevitable consequence of this change must be apparent to every one who is acquainted with the method of analysis so frequently resorted to by Dr. THOMSON. Many of the experiments described in his *First Principles of Chemistry* are now at irreconcilable variance with each other, and, if relied upon at all, subvert the conclusions which they once appeared to establish. Nor can those parts of his work which are not subject to this criticism be safely applied to the purposes of science. His view, for instance, of the composition of the compounds of oxygen with phosphorus, arsenic, and antimony, has been lately abandoned by himself*; and in the course of the present Essay I shall have occasion to prove, that the atomic weights which he has employed for silver and chlorine are likewise inadmissible. His analysis of sulphate of zinc, which was made, to use Dr. THOMSON's own words, "the foundation on which he endeavoured to rear the whole subsequent doctrine of the atomic weight of bodies†," is peculiarly objectionable. Besides being vitiated by his error in the equivalent of barium, the oxide of zinc was determined by a method which involved an error in principle, and was in practice so complex as to be unfit for the extremely important object which it was intended to serve.

Having shown that the atomic weights current among British chemists, though in some instances correct or sufficiently approximative, have, as a whole, been adopted on insufficient and fallacious evidence, I shall now lay before the Society an account of experiments made for ascertaining the equivalents of lead, chlorine, silver, barium, and nitrogen.

Equivalent of Lead.

BERZELIUS has made repeated and elaborate researches on the atomic weight of lead, and on the composition of its protoxide. His direct analysis of the oxide by reduction with hydrogen gas, simple as it appears, is liable to practical difficulties, the effect of which may be distinctly traced in the varying results of his experiments. Calculating from the two most discordant of the six analyses which BERZELIUS has published in his last Essay on this subject‡, the equivalent of lead, compared to oxygen as 8, will be 103.42 in one case, and 103.64 in the other. This difference, considering the simplicity of the method,

* *System of Chemistry*, Seventh Edition.

† *Annals of Philosophy*, vol. xxvi. p. 363.

‡ *POGGENDORFF'S Annalen*, vol. xix. p. 314.

and the large quantities of oxide subjected to analysis, is very far greater than could arise in the hands of BERZELIUS from the mere accidents of manipulation. One source of error, which however he appears wholly or in great measure to have avoided, is the tendency of the oxide of lead to unite with the siliceous matter of the tube, and thus to escape reduction. Another, not improbable, cause of slight error is referrible to the facility with which spurious distillation ensues when gaseous matter passes over the surface of a hot liquid: by this means small quantities of lead may have been carried away by the hydrogen, and the loss in oxygen thereby rendered too large. Hence the probability is, that the real equivalent of lead is nearer to 103.64 than to 103.42.

Seeing no chance of procuring by means of hydrogen more uniform results than BERZELIUS obtained, I selected an entirely different method, dependent on the quantity of sulphate of lead which given weights of metallic lead and protoxide of lead respectively produce. The method consists of a few simple operations, which, with the requisite precautions, may be conducted with ease and accuracy. A solution of the best commercial acetate of lead was precipitated by carbonate of ammonia in excess, and the carbonate of lead, after being well washed with distilled water, was dissolved in nitric acid. From the nitrate, purified by repeated crystallization, the lead was again thrown down by carbonate of ammonia, and the carbonate reduced by black flux. The metal was washed, fused in a clean crucible, and poured on a clean stone: before being used, the superficial film of oxide was scraped off with a penknife. In the lead thus prepared I could detect no silver, copper, or other impurity: 100 grains of the metal, oxidized, converted into sulphate, and ignited, yielded to hot water a mere trace of sulphate of potash corresponding to what was introduced by the water and acids which were employed.

Conversion of metallic Lead into Sulphate.—The mode which I found most convenient for converting the metal into sulphate, was to introduce it into the requisite quantity of mixed nitric and sulphuric acid, diluted with an equal volume of water. The vessel employed for the purpose was a small bell jar, such as is used for collecting gases over mercury: when placed in an inclined position on the sand-bath, there was no danger of loss by spirting, the materials could be freely stirred, and the sulphate readily removed by help of a clean feather at the close of the process. The excess of the acids was next decanted

into a platinum capsule two inches and a half in diameter, and expelled by evaporation. The sulphate of lead was then transferred to the same capsule, and gently evaporated to dryness, care being taken that some free sulphuric acid should be present. The capsule was then ignited by the flame of a spirit-lamp with a double wick, and its weight carefully taken before and after its contents were removed. The sulphate of lead should not be evaporated in a crucible, since otherwise the annoyance which **BERZELIUS** justly complained of, namely, loss by spirting, will be felt severely: by means of a capsule this inconvenience is entirely avoided. When the quantity of sulphate is abundant, it will be found convenient to transfer most of the salt to a crucible as soon as it is sufficiently dry to form a cake.

To prevent floating particles of dust from falling into the capsule during the evaporation, a disk of glass a foot in diameter was supported just above it, and the glass itself covered with a sheet of paper. Allowance was made for impurities contained in the water and acids. Each of these substances had been twice carefully distilled; but nevertheless, when evaporated, a trace of residue might be perceived: its quantity however was very minute. An ounce of nitric acid, four ounces of water, and 100 grains of sulphuric acid, (being twice as much of each as was employed in any single experiment,) were digested for a whole day on the sand-bath, and the residue was evaporated and ignited, every part of the operation being the same as in the conversion of lead into sulphate. The solid matter, consisting of the sulphates of lime and potash, amounted to 0.03 of a grain, half of which was therefore subtracted from the weight of ignited sulphate of lead in each experiment.

Another precaution, which ought not to be neglected in delicate atomic researches, was suggested to me by Dr. **CLARK** of Glasgow. In the conversion of lead into a sulphate, the same substance is weighed in two different states, its density in one form being 11.358, and 6.298 in the other,—a circumstance productive of a small error, which is appreciable when the difference between the two densities is considerable. I have always avoided this error, when it was of sufficient amount to affect the second place of decimals, by using absolute instead of apparent weights, that is, adding to the weight of each substance in air, the weight of the air which they respectively displace.

The quantity of sulphate of lead yielded by a given weight of metallic lead

is shown by the three following experiments, all corrections being allowed for. They were made after determining on the exact mode of manipulating by several previous trials :—

	Lead.		Sulphate.		Lead.	Sulphate.
Exp. 1.—	79·968	grains of metallic lead yielded	117·097,	being the ratio of	100 to	146·43
Exp. 2.—	63·257	_____	92·607	_____	_____	146·398
Exp. 3.—	92·92	_____	136·011	_____	_____	146·375

The mean of the three experiments gave 100 to 146·401

Four experiments of the same kind, published by **BERZELIUS**, gave the following numbers* :—

	1.	2.	3.	4.	Mean.
Lead . . .	100	100	100	100	100
Sulphate . . .	146·38	146·4	146·44	146·458	146·419

I adopt the ratio of 100 to 146·41 as being the mean of the whole.

Conversion of Oxide of Lead into Sulphate.—**BERZELIUS** has correctly shown that pure protoxide of lead cannot be prepared by decomposing the neutral nitrate by heat in a platinum crucible, since the crucible itself is always attacked, and the resulting oxide of lead intermixed with fine particles of platinum. To avoid this impurity, the oxide was prepared, as **BERZELIUS** recommends, from the subnitrate. To a cold solution of the neutral nitrate, pure ammonia was added in slight excess, and the white subnitrate collected on a filter, and dried. It was then introduced into a covered platinum crucible, and was heated for a full hour by a charcoal fire in an open grate, taking care to maintain it at a distinct red heat, but insufficient for fusion. The oxide was thus obtained in a pulverulent state, quite free from platinum, and of a pretty lemon-yellow colour. It ought to dissolve completely and easily in cold dilute acetic acid, yielding a colourless solution, which, on standing, does not deposit any brown particles of peroxide.

I may here mention the mode I adopt for weighing pulverulent or porous substances, so as to avoid the possibility of error from the condensation of air or moisture. The substance is well dried at the requisite temperature, and while hot is introduced into a small flask, capable of holding about an ounce of water, and of bearing a considerable temperature without breaking. The flask

* *Annals of Philosophy*, vol. xv. p. 96.

and its contents are placed in the sand-bath, and while yet hot a tight cork is inserted: the whole, when cold, is weighed, the required quantity for experiment gently poured out, and the flask again restored to the balance. By this means the weight even of a deliquescent substance may be exactly determined. It is necessary before the first weighing to restore the equilibrium of the air within the flask by a momentary removal of the cork.

A given weight of carefully prepared protoxide of lead was dissolved in hot dilute nitric acid, yielding a perfectly clear colourless solution, and the lead was thrown down by an excess of sulphuric acid. After evaporating the clear liquid, and expelling the nitric acid, the precipitate was transferred into the platinum capsule, and the quantity of sulphate determined in the manner already described. I subjoin several of my results, calculated to 100 parts, with all corrections made: the actual quantity of oxide employed in almost every case exceeded 100 grains. The numerals indicate the order of time in which the experiments were made:—

	1.	2.	3.	4.	5.	6.
Oxide . . .	100	100	100	100	100	100
Sulphate . . .	135·84	135·71	135·84	135·75	135·79	135·78

On comparing the second with the first and third experiments, it was manifest that there was some source of fallacy, since the difference was fully twice as great as I expected to arise from mere error in manipulation. I speedily traced one error by finding, in the second experiment, that some nitrate had escaped decomposition, and by ignition had been left as oxide. This was indicated by a yellow stain, and was proved by digesting the ignited sulphate with dilute nitric acid, when lead was readily taken up. This inconvenience was effectually avoided in the later experiments, by carefully expelling the nitric acid before bringing the precipitate into the capsule, and moistening it with a distinct excess of free sulphuric acid during evaporation.

Another fallacy, which affects all the results above quoted, arose from traces of red lead remaining in the oxide and eluding detection by being decomposed in the hot, rather strong dilute nitric acid which was used as the solvent. I was led to suspect this error by the escape of globules of gas while the oxide was dissolving; and accordingly on taking up a portion in cold acetic acid, the peroxide was readily brought into view. It was this circumstance which

induced me to express a belief, in a short report of these experiments to the British Association last June, that the equivalent of lead would be found rather higher than was then stated. Subsequent observation has justified that statement. Some pure protoxide of lead was prepared as before, and was then a second time kept at a red heat for a whole hour: it dissolved completely in cold dilute acetic acid; and 164·766 grains, treated as in the preceding experiments, yielded 223·943 of sulphate, being in the ratio of 100 to 135·92. Every part of this experiment was successfully performed, and I therefore confide in it as representing the true constitution of sulphate of lead. It is accordingly composed of.

Protoxide of lead	. .	164·766 grs.	. .	100	. .	73·575
Sulphuric acid	. . .	59·177 grs.	. .	35·92	. .	26·425
		223·943		135·92		100·000

Assuming, agreeably to the experiments already described (page 527), that 100 parts of metallic lead yield 146·41 of the sulphate, or that 100 of the sulphate contain 68·301 of metallic lead, it follows that the oxide consists of

Lead		68·301	. . .	103·6
Oxygen		5·274	. . .	8
		73·575		111·6

The equivalent of lead, according to these results, may be safely estimated at 103·6. It cannot be so high as 104, as is supposed by some British chemists; for according to the numbers current in this country, 100 of metallic lead ought to yield 146·16 of sulphate, instead of 146·41 found experimentally; and agreeably to the same estimates, 100 of the protoxide of lead should yield 135·72, instead of 135·92, the experimental quantity.

Equivalent of Chlorine.

The most conclusive experiments I have met with on this subject, are those of **BERZELIUS**. He obtained from 100 parts of chlorate of potash 39·15 of oxygen and 60·85 of chloride of potassium; and he also found that 100 of chloride of potassium correspond to 192·4 of chloride of silver. According to my own experiments, which coincide very closely with those of **BERZELIUS**,

100 parts of silver yield 132·8 of the chloride. From these data it follows that the equivalent of chlorine is 35·45.

Chloride of Lead.—To compare with this number the equivalent of chlorine deduced by a different process, some pure carbonate of lead was dissolved in muriatic acid diluted with boiling water, and the purity of the chloride ensured by repeated crystallization. The dry crystals were then fused in a tube filled with dry chlorine gas; and while the chloride was yet warm, the chlorine was displaced from the tube by dry carbonic acid gas. The resulting chloride of lead was colourless, and dissolved completely in hot water. The analysis was performed by decomposing the solution of chloride of lead by carbonate of soda, acidulating the clear solution with nitric acid, and precipitating with nitrate of silver. The carbonate of lead, after being washed, was dissolved in acetic acid, and tested for chlorine. The quantity of chlorine was inferred from the quantity of chloride of silver, and that of lead from the quantity of chlorine. After a few repetitions I obtained uniform results, and subjoin the proportions of the two most successful experiments:

	1.		2.	
Lead	19·582	103·6	23·099	103·6
Chlorine	6·708	35·48	7·901	35·43

These results, then, give an equivalent for chlorine closely agreeing with that calculated from the analysis of chlorate of potash as above quoted from **BERZELIUS**. They are, at the same time, entirely inconsistent with the atomic weights current in this country. For, supposing 104, 36, and 110 to be the respective equivalents of lead, chlorine, and silver, it follows that 100 parts of the chloride of lead should yield 104·28 parts of chloride of silver, instead of 103·24 as given by experiment,—a difference very far beyond the reasonable limits of error.

Oxide of Mercury.—Wishing to obtain still further evidence respecting the ratio of the atoms of chlorine and oxygen, I determined on performing a careful comparative analysis of the binoxide and bichloride of mercury. I at first employed some red oxide prepared by myself from the nitrate; and though the analyses made with that substance are subject to a slight error, yet as the side on which the error lies is apparent, it will not be unprofitable to record them. A quantity of oxide of mercury was decomposed in a porcelain retort by a red

heat, and the mercury was received in distilled water. It was well boiled successively with muriatic acid, potash, muriatic acid, and distilled water. The pure metal was oxidized by very pure nitric acid, and the nitrate decomposed by heat, the temperature at the last being urged so fully to a decomposing heat, that some metallic mercury sublimed. This was done to decompose every trace of nitric acid, and it succeeded to a very great extent; but when considerable quantities of the oxide, such as 150 grains, were decomposed by heat, the sublimed mercury exhibited a faint yellow ring, indicative of a small quantity of nitric acid. Even digestion with a solution of potash did not prevent this appearance.

The method of analysis was by the direct action of heat. A given weight of the red oxide, previously exposed to a heat of 600° to expel all trace of metallic mercury, was introduced into a tube of German glass, five eighths of an inch wide, and about ten inches in length; and the oxide was decomposed by the flame of a spirit-lamp, the remainder of the tube being kept cool by moistened paper. The gas as it escaped passed through a bent narrow tube, containing pieces of silver, and ultimately passed over a surface of gold-leaf: this tube was weighed at the beginning and close of each experiment, but in general the quantity of mercury conveyed into it was not appreciable. When the decomposition was complete, the tube was filled with dry carbonic acid gas, and the metal was again distilled. The subjoined numbers contain the results of two experiments performed after acquiring experience in the manual part of the method by several previous trials:

	1.		2.	
Mercury	144.805 grs.	200.768	125.98 grs.	199.968
Oxygen	11.54 grs.	16	10.08 grs.	16

The figures at the left hand of each bracket indicate the quantities actually observed. The oxide employed in the two analyses was prepared at different times. Neither portion was wholly free from nitric acid; and hence it is apparent, as the loss was thereby rendered greater than it ought to be, that the real equivalent of mercury must exceed 200.768.

I next proceeded to analyse peroxide of mercury prepared by heat; and for that purpose a number of pure scales was selected from among a large sample of commercial oxide. On exposure to a temperature of 600° , a portion of me-

tallic mercury was expelled, and the colour of the oxide brightened; indeed, every specimen of oxide which has fallen into my hands contained some free mercury, separable by heat, and due, I presume, to the deoxidizing agency of light. A similar remark was made some years ago by Professor DANIELL. The sample analysed contained likewise 0·01 per cent. of fixed matter, which was silica or peroxide of tin coloured by iron, together with a little lime. Allowance was of course made for it. The following is the result of two careful analyses:

	1.		2.	
Mercury	173·561	grs. 200·94	114·294	grs. 200·93
Oxygen	13·82	grs. 16	9·101	grs. 16

From this it would seem that the equivalent of mercury is not 200 as commonly believed by British chemists, but about 201. For the moment, I adopt this number, and will revert to the subject afterwards.

Bichloride of Mercury.—The corrosive sublimate of commerce was purified by repeated crystallization from distilled water, and was then well dried at its subliming temperature. It might in that state be sublimed without giving any trace of humidity. Of this chloride 137·595 grains were dissolved in warm water, and directly decomposed by nitrate of silver; and the chloride of silver was washed with water acidulated with nitric acid, and amounted in the fused state to 144·374 grains, equivalent to 35·659 of chlorine. The bichloride of mercury would hence seem to be composed of

Mercury	101·936		201
Chlorine	35·659		70·31

giving 35·16 as the equivalent of chlorine. This result led me to suspect some imperfection in the method of analysis; and I accordingly found that some of the bichloride of mercury is apt to combine with the chloride of silver, and being expelled when the latter is fused, a loss of chlorine is occasioned. To avoid this error, the bichloride was decomposed by lime, which was prepared from Carrara marble, and was quite free from muriatic acid. The requisite quantity of lime, previously slaked, was mixed with a little warm water, and the solution of a known weight of corrosive sublimate gradually added, shaking the mixture after each addition. After a short digestion and filtration, the

liquid was neutralized by nitric acid, and the chlorine determined by nitrate of silver in the usual manner. Every trace of muriatic acid may thus, without the necessity of boiling the materials together, be transferred to the lime and rendered soluble, while the oxide of mercury, of an orange colour, is left with the excess of lime. In this way I obtained the three following ratios:—

	1.	2.	3.
Mercury	113·441 . . 201	113·149 . . 201	112·535 201
Chlorine	39·748 . . 70·428	39·723 . . 70·565	39·433 70·43

According to these results we obtain 35·214, 35·28, 35·26 as the equivalent of chlorine.

Calomel.—The proto-chloride, though much more stable than the protoxide of mercury, is very subject to change. I believe it is impossible to sublime calomel without a portion being resolved into mercury and corrosive sublimate; and after washing calomel, so as to remove the adhering bichloride, the heat subsequently required for rendering it quite dry causes a fresh production of corrosive sublimate. I selected for analysis the pulverulent white calomel prepared by Mr. HOWARD, and dried it by exposure to a continued heat of 300° FAHR.; at which temperature it undergoes no appreciable decomposition, and contains only a trace of moisture. But that trace of humidity affects the ensuing results with a small error, the tendency of which is to make the equivalent of chlorine smaller than it is. The following are the ratios of three careful analyses, which were made by means of lime, as in the analysis of corrosive sublimate.

	1.	2.	3.
Mercury	100·048 . . 201	95·154 . . 201	76·565 . . 201
Chlorine	17·602 . . 35·361	16·721 . . 35·32	13·473 . . 35·37.

It will now be convenient to compare together the numbers expressive of the equivalent of chlorine as determined from the four sources above enumerated: these are

	From Chlorate of Potash, (BRANGLIUS.)	Chloride of Lead.	Bichloride of Mercury.	Protochloride of Mercury.
Equivalent of chlorine . . .	35·45	35·45	35·28	35·35.

The equivalent of chlorine is thus limited by the numbers 35·28 and 35·45, and the mean is 35·33. Though this number has been obtained by four distinct methods, yet there is one element of the calculation common to all,

MDCCCXXXIII.

3 z .

namely, the composition of chloride of silver. Should any material error exist in this fundamental point, a doubt may still be raised respecting the equivalent of chlorine; but if we can rely on the constitution of the chloride of silver as here employed, then I should feel no hesitation in confining the equivalent of chlorine within the limits which have just been assigned. Now it happens that on this very question a doubt has been raised by my friend Dr. Prout, whose remarks are always pertinent, being founded on careful observation. Chloride of silver, as Dr. Prout informs me, invariably gives out muriatic acid at a certain stage of drying; and he suggests whether the loss may not be sufficient to influence the atomic weight of chlorine. Into this point I have carefully examined. Nitrate of silver was precipitated by muriatic acid in excess, was well washed with warm water, and set to drain in a dark closet. Exposed to light it acquired an acid reaction; and heated in contact with litmus-paper, the colour was reddened, even though not at the same time under the influence of light. A portion was introduced into a clean retort, and heat applied so as to dry it in that situation, day-light being excluded: the water which thus came over was quite neutral, and the chloride was at length left quite white and dry, without a trace of acid being lost. The same experiment was repeated with the same result. I hence consider it as certain that pure chloride of silver may be completely dried at 300° FAHR. without loss of any acid, if light and organic matter be excluded. On heating this dry and white chloride in a test-tube, a portion of acid sufficient to redden litmus was given out, just as the colour of the chloride darkened in the act of fusing. This phenomenon is constant. To try the amount of the loss, a quantity of pure chloride of silver was well dried at 300° FAHR.; and in one experiment forty-one grains, and in another ninety grains, were fused in a platinum crucible. In neither case did the loss amount to an appreciable quantity: I could not satisfy myself that it reached 0.01 of a grain. In these trials, however, the dry chloride was corked up in the weighing flask while still warm; for if allowed to cool in the open air, it absorbs a little air and moisture, and then on being fused a slight loss is perceptible. These experiments have been preferably made with chloride of silver thrown down from the nitrate by muriatic acid: the results are similar with any pure chloride; but when precipitated by sea-salt, it is apt, unless very carefully washed, to retain a little chloride of sodium, and then I

believe the developement of acid is more easy than when the chloride of silver is quite pure.

The foregoing experiments have given me the most perfect conviction that my estimate of the constitution of hornsilver, deduced from the researches published in my last Essay, is in no wise vitiated by the fact noticed by Dr. PROUT. But in order, on a point of so much practical and theoretical interest, not to omit any evidence which might elucidate the subject, I endeavoured to analyse corrosive sublimate by directly ascertaining the quantity of mercury which it contains. For this purpose a quantity of grain tin was oxidized by nitric acid, and the resulting oxide, after being washed and ignited, was reduced by charcoal. The pure tin, after being granulated and washed, was dissolved in strong muriatic acid. The solution was colourless and transparent, and an excess of acid was added to it. The reduction of the bichloride was thus effected. A given weight of the compound was dissolved in a small quantity of hot water acidulated with muriatic acid, and the protochloride of tin, likewise hot, was added in excess. A tube twelve inches long, surrounded by a moist cloth, was then attached to the flask containing the mixture, and ebullition was kept up for a few minutes, the extremity of the tube being closed by the finger. This precaution was taken in order to prevent, as far as possible, loss of mercury by the ebullition which is required for collecting together the finely divided metal. Most of the mercury was thus obtained in one bright globule: it was fully washed by tepid water acidulated with muriatic acid, and the decanted washings were set aside till the suspended particles had subsided. The mercury was ultimately collected on a double filter, which was dried under a bell-jar with a vessel of sulphuric acid, the air at the close being rarified. The two most successful experiments supply the following numbers:—

	1.			2.	
Mercury	44.782	201		73.09	201
Chlorine	15.90	71.366		25.97	71.413.

I should be unwilling to adduce these experiments as giving an exact view of the composition of corrosive sublimate, because the chlorine is inferred from the quantity of mercury collected, and the mercury is obtained by a method in which a small loss is, I believe, unavoidable. They answer the purpose, however, which they were intended to serve. For in giving 35.67 as the equivalent of chlorine, they show the highest practicable number; because, since

the mercury obtained was pure and dry, its quantity could not represent less than was present in the compound subjected to analysis. It may have contained more, but not less mercury than was collected; and any quantity to be added to that above given would proportionally diminish the quantity of chlorine. Thus, if these analyses are at all trustworthy, they prove that the equivalent of chlorine may be less than 35·7, but that it cannot be greater.

There seems, therefore, to be no reason to call in question the methods which have been used to find the equivalent of chlorine. The real number, as above stated, is to be sought within a range extending from 35·28 to 35·45. This range may be much narrowed by facts supplied by other experiments. Were 35·35 assumed as the equivalent of chlorine, 107·78 would be the equivalent of silver, deducible from the composition of chloride of silver; but this number for silver is inconsistent with the analysis of nitrate of silver to be afterwards mentioned, and consequently the hypothesis which led to it is inadmissible. By a similar line of reasoning the equivalent of chlorine may be brought within the limits 35·4 and 35·45. I am disposed to select 35·42 as agreeing closely with my own results, coinciding with the number given in the most recent tables of BERZELIUS, and as giving a convenient number for silver.

Equivalent of Silver.

It appears, at first sight, such a simple operation to prepare oxide of silver, and to reduce that oxide by heat, that my first attempts to ascertain the atomic weight of silver were made with that compound. It was soon apparent, however, by want of uniformity in my results, that some fallacy existed; and after numerous unsuccessful efforts to detect it, I abandoned the method altogether. The examination of sulphuret of silver was likewise begun, and subsequently abandoned for a similar reason. The analysis of the oxide was thought of as a means of comparing the equivalents of oxygen and chlorine through the medium of silver; but as this object has been attained by other means, it is easy to infer the equivalent of silver by the constitution of the chloride. In the belief that 100 parts of silver unite with 32·8 of chlorine, the atomic weight of silver will be 107·92, 108, or 108·08, according as we adopt 35·4, 35·42, or 35·45, as the equivalent of chlorine. As the whole number has as equal a chance of being correct as either of the others, it may be adopted with propriety, and is certainly a very close approximation.

Equivalent of Barium.

The atomic weight of barium may be calculated from my analysis of the chloride of barium already published in the Philosophical Transactions. According to the proportions there stated, 100 parts of the chloride consist of 65·984 of barium and 34·016 of chlorine; the equivalent of barium is therefore 68·7, that of chlorine being 35·42. The analysis of *BERZELIUS* differs slightly from mine, giving 68·53 as the equivalent of barium. I adopt 68·7, as confiding in the indications of frequently repeated experiments; but at present I have no other proof that this number is more exact than that employed by *BERZELIUS*; it appears certain that 69 is too high, and that 68 is too low, being incompatible with our analyses.

Equivalent of Nitrogen.

I have endeavoured to ascertain the equivalent of nitrogen by the analysis of the nitrates of silver, lead, and baryta.

Nitrate of Silver.—Pure silver was oxidized and dissolved in nitric acid, and the concentrated hot solution set aside. In cooling, it deposited numerous transparent thin tabular crystals, which were fused, redissolved in water, evaporated, and again kept for some time in a state of fusion. The fused nitrate was quite colourless, and dissolved in water without the least turbidity. It was analysed by solution in water and precipitation by muriatic acid; the whole was transferred to a porcelain capsule, evaporated on the sand-bath to perfect dryness, being protected at the same time from dust and light, and was then fused. The impurity introduced by the acid and water employed in each analysis amounted to 0·01 of a grain, which was subtracted from the whole weight obtained. The following is the result of two very successful analyses, made after several preliminary and less satisfactory experiments:—

	1.				2.			
Nitrate of silver . . .	124·892	grs.	100	118·544	97·992	grs.	100	118·5
Fused chloride of silver	105·355	grs.	84·357	100	82·695	grs.	84·389	100.

It may therefore be inferred, as a mean of these closely corresponding ratios, that 100 parts of the fused chloride corresponds to 118·522 of the fused nitrate of silver. By the analysis of chloride of silver, 100 parts contain 75·3012 of metallic silver, corresponding to 80·87 of oxide, the equivalent of silver being 108.

Hence 118·522 parts of nitrate of silver contain 80·87 of oxide and 37·652 of nitric acid; and on subtracting from this quantity of acid five times the oxygen of the oxide of silver, viz. 27·844, there remain 9·808 of nitrogen. The equivalent of nitrogen, calculated from these numbers, is 14·09.

Nitrate of Lead.—Carefully prepared nitrate of lead was reduced to a very fine powder, and then dried at a temperature of 300°. It is not safe to expose this salt to a temperature much beyond 300° FAHR., as it is apt, when so heated, to suffer partial decomposition: perfect desiccation must be secured by fine levigation, and the continued action of a comparatively moderate heat. Known quantities of the salt were then dissolved in distilled water, and decomposed by an excess of sulphuric acid; and the resulting sulphate was collected in the same manner and with the same precautions as were described in a former part of this Essay, (page 526–528.). The following is the result of three successful experiments:—

	1.		2.		3.	
Nitrate of lead . .	132	grs. . . 109·312	99·888	grs. . . 109·31	130·122	grs. . . 109·3
Sulphate of lead . .	120·755	grs. . . 100	91·38	grs. . . 100	119·05	grs. . . 100.

As a mean of these analyses, it follows that 109·307 parts of nitrate yield 100 of sulphate of lead; and it has already been shown that the latter contain 73·575 parts of oxide, and 68·301 of metallic lead. From these data, and by the same mode of reasoning as was applied to nitrate of silver, it follows that 14·201 is the equivalent of nitrogen.

Nitrate of Baryta.—This salt was prepared from the native carbonate, and was purified by repeated crystallization; no impurity could be detected in it, and it was especially examined, by well known tests, for lead and strontia. It was converted into sulphate in the same manner and with the same precautions as were explained in the experiments with lead. It was dried by being reduced to a fine powder, and exposed to a temperature of 500°.

The following is the result of three satisfactorily conducted analyses, performed after several preparatory trials:—

	1.		2.		3.	
Nitrate of baryta . .	92·83	grs. . . 112·06	97·38	grs. . . 111·99	121·391	grs. . . 112·035
Sulphate of baryta . .	82·84	grs. . . 100	86·955	grs. . . 100	108·35	grs. . . 100.

As a mean of these analyses it appears that 112·028 parts of nitrate yield 100 of sulphate of baryta, which contain 65·669 of baryta and 58·8195 of

barium. Hence, as in the former instances, it may be calculated that 14·17 is the atomic weight of nitrogen. It is assumed in this calculation that 68·7 is the equivalent of barium, and that 100 parts of chloride of barium contain 65·984 of barium, and correspond to 112·18 of sulphate of baryta.

The equivalent of nitrogen thus appears to be somewhere between the numbers 14·09 and 14·2, and the mean is 14·15, which corresponds closely with the number selected by BERZELIUS from his analysis of nitrate of lead. It must be admitted, however, that this mode of deducing the equivalent of nitrogen is not a desirable one, since the slightest error in the equivalents of silver, lead, and barium is multiplied five times in estimating the composition of nitric acid. The united testimony of three independent sets of experiments (or rather four, including the analysis of BERZELIUS,) serves to diminish the force of this objection; but still chemists must give a preference to the more direct method, founded on an exact determination of the densities of oxygen and nitrogen gases, such as we anticipate from the labours of Dr. PROUT.

Equivalent of Sulphur.

I have not yet entered upon a systematic investigation of the atomic weight of sulphur, but merely purpose, on the present occasion, to extract the information which flows incidentally out of the researches in which I have been occupied. It has been shown that 100 parts of sulphate of lead consist of 26·425 of sulphuric acid and 73·575 oxide of lead, which last contain 5·274 of oxygen. From these data, coupled with the known atomic constitution of sulphuric acid, it follows that this acid is composed of

Sulphur	10·603 . . .	16·083
Oxygen	15·822 . . .	24
	26·425	40·083

Similarly, from the estimates above given, it follows that 100 parts of sulphate of baryta consist of 34·331 of sulphuric acid and 65·669 of baryta, which contain 6·8495 of oxygen. Hence it follows that sulphuric acid is composed of

Sulphur	13·7825 . . .	16·097
Oxygen	20·5485 . . .	24
	34·3310	40·097.

These estimates agree closely with that of **BERZELIUS**, deduced by a similar method. Though in some measure subject to the criticism already referred to in the foregoing observations on nitrogen, they leave no doubt on my mind of the equivalent of sulphur being rather more than exactly double the equivalent of oxygen. I hope, however, to examine this point more narrowly on a future occasion.

Equivalent of Mercury.

The principal experiments which have been published on the equivalent of mercury are by **SEFSTRÖM** and **DONOVAN**. According to three analyses of the red oxide of mercury by **SEFSTRÖM**, the results of which are given in the *Annals of Philosophy**, 16 parts of oxygen unite with 202·78, 202·54, 200·24 of mercury. **DONOVAN** found the peroxide to consist of 16 parts of oxygen and 204·6 of mercury, and the protoxide of 8 of oxygen and 194·2 of mercury. It is difficult from such very discordant results to strike any mean which should be moderately trustworthy. **DONOVAN**'s analysis of the protoxide is of no use, as that compound is so very unstable as to be wholly unfit for atomic researches; and his analysis of the peroxide must certainly be erroneous, owing, perhaps, to his having overlooked the presence of metallic mercury in the peroxide which he examined. Even the analyses of **SEFSTRÖM** indicate that the equivalent of mercury lies within the somewhat wide range extending from 200·24 to 202·78. The number may be brought within a narrower limit by the researches already described in this Essay. The equivalent deduced from the analyses of the red oxide is 200·94 and 200·93: the three analyses of calomel, taking the atomic weight of chlorine as 35·42, give 201·28, 201·3, and 201·57, of which the mean is 201·38, as the equivalent of mercury; and the numbers deducible from the three analyses of corrosive sublimate are 201·78, 202·16, and 202·18, of which 202·04 is the mean. Thus the equivalent is included within the numbers 200·93 and 202·18. Moreover, it will be remembered, that on calculating the equivalent of chlorine on the hypothesis of 201 being the real equivalent of mercury, an error was committed, which involved the alternative, either that 201 was too low, owing to a slight error in the analysis of the oxide of mercury, or that all the analyses of calomel and

* iii. 355.

corrosive sublimate were inaccurate. The latter supposition is very much less probable than the former. With regard to the relative value of the experiments made with calomel and corrosive sublimate, I rely most on the analyses of the latter, since it is much more stable as regards the action of heat, and hence more certainly obtained in a pure state than calomel. I therefore infer that 202 may be considered as a close approximation to the real equivalent of mercury.

Before closing this communication, I will avail myself of the opportunity to make a few remarks on the employment of filters. In so far, indeed, as respects the experiments which have been described in the present and preceding Essay, the discussion is not very material, since most of the principal facts have been ascertained by processes independent of filtration; but in reference to analysis in general, the subject is very important. In my own researches I am in the habit of determining the weight of substances collected on a filter in one of three different ways. One of these, introduced by **BERZELIUS**, consists in burning the filter in a platinum crucible, and deducting the weight of its ashes. This method is peculiarly applicable to the analysis of minerals, where such substances as silica, alumina, and lime are frequent. Even some substances of easy reduction, such as peroxide of iron and sulphate of baryta, may be safely treated in the same way; but in these cases it is advisable not only, as usual, to separate the mass of the precipitate from the filter before setting it on fire, but to moisten both with a little nitric acid, and to ensure very free exposure to the air during the burning of the paper and the subsequent ignition. For such purposes I commonly use some excellent Swedish filtering paper, kindly procured for me by **BERZELIUS**.

Another method is that of the double filter, introduced by **Dr. THOMSON**, which I have used in all the experiments where filtration is spoken of in the present and former communication. Both **BERZELIUS** and **Dr. THOMSON** himself seem inclined to doubt the accuracy of this method; and it is certainly liable to objection, except with certain precautions and with very compact filtering paper. The paper which I use for the double filter is considerably thicker than the Swedish paper, and of such compact texture that recently precipitated oxalate of lime, or sulphate of baryta thrown down by **GLAUBER'S** salt in a neutral solution of the chloride of barium, may be filtered by it. The

precautions employed are these. The paper, folded into filters, is macerated in dilute nitric acid for two days, is then fully washed with warm distilled water, and dried at a temperature of about 212° FAHR. After acquiring its hygrometric moisture, two of the filters of nearly the same weight are poised against each other, and any small difference marked in pencil on the lighter one. Before being used, a pin-hole is made in the outer filter, in order that any accidental imperfection in the inner filter should be made apparent. After filtration both filters are dried at the same temperature, and are afterwards allowed to recover their hygrometric moisture completely before removal to the balance. In repeated trials I have found a pair of filters to recover, after use, their original relation in weight to within the 100dth part of a grain; nor have I ever noticed a greater deviation than may well be expected in every process where filtration is concerned. Additional testimony of the same kind will be found in my Essay printed in the Philosophical Transactions for 1819, where, in two sets of experiments, the same point is investigated by the use of double filters and by evaporating the precipitate to dryness without filtration. The series with silver, moreover, are interesting in reference to the remarks of Dr. PROUT above noticed (p. 534); for it is manifest from those results that chloride of silver may be collected on paper and dried, (in my experiments the filters were dried in a dark, warm air-closet,) without appreciable loss of acid.

A third method consists in employing a single filter, which is dried before and after filtration at some fixed temperature, as at 212° FAHR.; and when so dried is inclosed in a light silver vessel, the cover of which is tightly fitted by grinding. The filter may thus be deliberately weighed without absorbing moisture during the operation. In case of its being inconvenient to employ an uniform temperature, the filter may be dried at a variable heat, be allowed to absorb hygrometric moisture, and afterwards kept at about 60° FAHR. for two hours in a closed bottle, the bottom of which is covered with pulverized quicklime. In this method, while operating at least with paper of British manufacture, it is essential, more so than with the double filter, to have previously macerated the filter in dilute acid; for all such paper, which I have examined, contains lime.

I now, in conclusion, subjoin a list of the atomic weights ascertained by the researches described in the present communication, and add for the conve-

nience of comparison the corresponding numbers of **BERZELIUS** from his latest table of equivalents*, as well as those published by **Dr. THOMSON** in his *First Principles of Chemistry*.

	THOMSON.	BERZELIUS.	TURNER.
Lead	104 . . .	103·5598	103·6
Silver	110 . . .	108·1285	108
Chlorine	36 . . .	35·412	35·42
Barium	70 . . .	68·5504	68·7
Mercury	200 . . .	202·5315 (SEFSTRÖM.)	202
Nitrogen	14 . . .	14·1628	14·15
Sulphur	16 . . .	16·0932	16·09

The equivalents fixed on by **BERZELIUS** are in general substantially the same as mine. I have had continual opportunities of witnessing the extreme care which he employs in his experiments, as well as the fairness with which he reports them. His estimates, when directly drawn from his own experiments, are in general very close approximations. The chief difference between us is in the mode of representing equivalents: **BERZELIUS** strikes a mean of his results, and then calculates the atomic weight to a number of decimal places, which, in general, far exceed the degree of approximation justified by experiment; whereas I calculate extreme equivalents, and take the mean of them, rejecting all decimals which follow the first doubtful figure. Thus the two last decimals in his equivalent of lead are useless; since the experiments of **BERZELIUS** leave it doubtful whether the equivalent of lead may not fall short of 103·55 instead of exceeding that number. This doubt respecting lead again operates on the equivalents of nitrogen and sulphur; so that it is doubtful if the equivalents of these elements may not be smaller instead of greater than 14·16 and 16·09.

With regard to the numbers employed by British chemists, it is apparent that they are in many instances inconsistent with experiment. Numbers asserted to be correct to a minute fraction of a unit, are found in error to the extent of a unit and a half, or two entire units: the equivalent of silver, for instance, instead of being 110, is exactly or nearly 108; and the equivalent of barium has been reduced by **Dr. THOMSON** himself from 70 to 68. The atomic weights

* **POGGENDORFF's Annalen**, xxi. 614.

of chlorine and lead are likewise incorrect ; and thus are found to be erroneous four quantities which have been employed as elements in calculating the equivalents of nearly all the other elementary substances. Under such circumstances, Dr. Prout's hypothesis, as advocated by Dr. Thomson,—that all atomic weights are simple multiples of that of hydrogen,—can no longer be maintained. I grant most willingly, that a system of whole numbers, considered as moderate approximations, may, with advantage, be retained for the use of medical men, students, and manufacturers ; but as the strict representative of scientific truth, applicable to all the purposes of science, this hypothesis is at present untenable. Let me not however be misunderstood : I mean simply to affirm that the experiments by which it has been attempted to prove the truth of this hypothesis are inaccurate : I may go further, and declare it to be not only unsupported by evidence, but to be at variance with the most exact analytic researches which have been conducted. I deny not that some simple relation subsists among atomic weights, and that their ratios may possibly be expressed by some simple series of numbers ; but at present no one has assigned any physical cause for the existence of such a relation ; no such relation has hitherto been discovered ; nor, as appears to me, has analytic chemistry attained that degree of perfection which can justify any one in finally asserting or denying its existence.

XXII. *Note on a Paper by Dr. JOHN DAVY, entitled "Notice on the remains of the recent Volcano in the Mediterranean." By CHARLES DAUBENY, M.D. F.R.S., Professor of Chemistry in the University of Oxford.*

Received May 13,—Read May 16, 1833.

AT the request of the Council of the Royal Society, I propose to submit the following remarks on a paper of Dr. JOHN DAVY's that has recently been read on the subject of the new volcanic island lately thrown up in the Mediterranean ; being desirous of directing the attention of men of science in a more particular manner to the examination of the gases evolved by volcanos, and likewise of pointing out to them certain objections which appear to militate against the hypothesis, by which, in the communication alluded to, the disengagement of nitrogen, accompanied with only half the proportion of oxygen present with it in atmospheric air, is accounted for.

Nitrogen gas has not hitherto, I believe, been often observed to issue from volcanos in action ; but the frequent presence of ammoniacal salts amongst the vapours given off by them affords a fair presumption that, if looked for, the gas itself might be found to occur more commonly ; especially as the great majority of hot springs—whether such as are immediately and confessedly connected with volcanos, as that of Castella, near Naples, or that more numerous class which are supposed by many geologists (though without such direct evidence,) to owe their temperature to causes of an analogous nature,—copiously evolve it, often in a state of purity, but sometimes, as in the specimen examined by Dr. DAVY, intermixed with a certain proportion of oxygen*.

Under such circumstances, the more obvious conclusion would seem to be,

* Having given the details of this subject already, in a paper "On Thermal Waters and their Connexion with Volcanos," published in the *Edinburgh New Philosophical Journal*, conducted by Professor JAMESON, for 1831, I will here only state that the evolution of nitrogen, which was discovered long ago by Dr. PRIESTLEY at Bath, and by Dr. PEARSON at Buxton, has been lately found by myself

that the evolution of this gas is in some way or other connected with certain chemical processes going on at, or near the place of its occurrence. And in this point of view any account relating to the phenomenon in question derives an interest beyond what it would obtain according to Dr. DAVY's mode of considering it, as being calculated in a more especial manner to afford us a clue to the hidden causes of volcanic action in general.

It may therefore not appear irrelevant, if I proceed to point out certain objections that have occurred to me with reference to the latter portion of Dr. DAVY's paper; in which nothing more than the mere evolution of the gas is attributed to the volcano itself; whilst the absence of a portion of that oxygen which accompanies it in common air, is resolved into putrefactive processes, going on generally at the bottom of the sea, and therefore wholly unconnected with the particular nature of the locality.

I would observe in the first place, that the notion of sea-water at great depths being wholly or partially deprived of its oxygen by animal putrefaction, &c., seems inconsistent with the general analogy of nature, since in all other cases there appear to be counteracting causes which restore to the air its purity; and that notwithstanding the rapid diminution of light in descending through so dense a medium as water, still the existence, at great depths, of Algæ possessing an intensely green colour would seem to indicate, that the decomposition of carbonic acid is going on there as well as upon land. Indeed, owing to the constant circulation taking place in every mass of water, especially if supposed to rest upon a heated substratum, any influence that might be exerted upon the nature of the air contained would be quickly spread over the whole body of the sea, instead of being limited to its inferior portions, where, moreover, the very existence of animals, which must imbibe this air, leads us to conclude, that no material difference in its quality could obtain.

Granting even the nature of the air contained in sea-water at the bottom of the Mediterranean to be such as Dr. DAVY represents, I do not understand

to take place also at Bakewell and Stony Middleton, in Derbyshire, and at Taafé's Well, near Cardiff in South Wales;—that I have likewise detected it issuing from the hot springs of Mont Dor, and Chaudesaignes in central France, and those of St. Gervais, Cormayeur, St. Didier, and Bonneval in Savoy;—and that Longchamp states its occurrence at Vichy and in all the thermal waters at the foot of the Pyrenees. Other instances are mentioned in the paper referred to.

how it can find its way to the surface, in consequence merely of the high temperature to which it is subjected below. Either, in this situation, the pressure of the superincumbent mass of fluid is sufficient to prevent the conversion of the lower strata of water into steam, or it is not. If it be, this same pressure will enable the water to retain in solution its original quantity of air, or at least the greater proportion of it. If, on the contrary, there be not sufficient pressure for the purpose, then no doubt the water will rise up in the form of steam through the superincumbent mass along with the air which it had contained; but as the temperature of the sea round about the volcano, at least near its surface, is stated by Dr. DAVY not to be higher than that of the atmosphere, it is plain that all the steam must become rapidly condensed, and when it returns to its liquid state, there seems no reason why it should not exert its affinity for the air intermixed, and combine with it as before.

For these reasons, amongst others, I conceive that the air which Dr. DAVY examined cannot have been derived from sea-water, but must have originated from the atmosphere itself, with which this volcano, from its contiguity to Malta and Sicily, may with less difficulty be supposed to communicate; and this is favoured by the probable upheaving of the bed of the Mediterranean underneath the spot at which the island made its appearance; for the proofs of which I may appeal to the memoir of Captain SMYTH, lately published in the Transactions, as an Appendix to Dr. DAVY's former paper on this subject.

Now the upheaving of the bed of the sea would imply the existence of hollows or caverns underneath, into some of which, if not in immediate connexion with the water above, atmospheric air would doubtless find admission.

I would also observe, that if the quantity of gas emitted bore any proportion, as Captain SWINBURNE states it did, to that observed in chalybeate springs, so constant a supply could hardly have been derived from such a source as sea-water; for 100 cubic inches of pure distilled water (which holds in solution rather more air than sea-water will do,) only contain about one cubic inch and a half of nitrogen; and in most thermal waters that have been examined, the evolution of this gas is much more copious than it is here represented, and makes its appearance in large and frequent bubbles, and not "in minute silver threads."

In a word, I conceive that Dr. DAVY has under-rated the interest which

ought to attach to the information he has afforded respecting the gases given off on the site of this new volcano, by explaining their composition on principles unconnected with volcanic action ; whereas a higher importance really attaches to them, if considered, as it appears they ought to be, intimately related to the latter train of effects.

As, however, our estimate of his theory (at least as extended to the case of thermal waters,) may in part depend upon the quantity of gas evolved in a given time, it is to be regretted that no accurate statements of this have as yet, so far as I am aware, been published ; and I therefore would invite such men of science as may chance to be conveniently situated for such researches, to examine the volume of gas emitted by some of our own warm springs, as by those at Bath or Buxton ; which inquiry, indeed, I hope at some future time to undertake myself, should not the necessity for it be superseded by the previous investigations of others.

XXIII. *Observations of the Comet of Encke, made in June 1832.* By THOMAS HENDERSON, Esq., *HIS MAJESTY'S Astronomer at the Cape of Good Hope.* Communicated, by Command of the Lords Commissioners of the Admiralty, by Captain BEAUFORT, R.N., F.R.S., *Hydrographer to the Admiralty.*

Received May 17,—Read May 24, 1833.

THE following observations (excepting those with the transit instrument,) were made with a circular micrometer, constructed by SIMMS, and applied to an achromatic telescope of DOLLOND, forty-five inches in focal length, and three and a half inches aperture, furnished with a portable equatorial stand, which can be adjusted to any latitude. By means of the horary and declination circles, and the difference of right ascension and declination betwixt the comet and the nearest bright star, the telescope was readily pointed to the comet's place; but when the comet got to the southward of the zenith, and was near the meridian, the equatorial apparatus became useless, as its supports came in the way of the telescope: the telescope was then pointed to the comet according to the best estimate which the eye could make of its place in the heavens relatively to the neighbouring stars. The instrument was placed either at one of the windows of the Observatory building, or out of doors in a corner sheltered from the wind, where the best view of the quarter of the heavens where the comet was situated could be obtained. The magnifying power employed was thirty-two, and the radius of the ring was found to be 1015 seconds of arc.

The transit instrument by DOLLOND is nearly ten feet in focal length, and the object-glass is five inches in diameter. For observing the comet, an eye-glass, magnifying eighty-eight times (the lowest power which it possesses), was used.

June 2nd.—The times are reckoned according to the chronometer, French, No. 975, which was gaining 13·4 seconds per diem on mean solar time: 9^h 44^m 12^s by the chronometer corresponded to 17^h 22^m 6^s mean time.

MDCCCXXXIII.

4 B

The comet was first perceived about 16^h 54^m mean time, when it had attained an altitude of $6\frac{3}{4}^{\circ}$ above the horizon, the sun being then 25° below the horizon. It was seen at once on directing the telescope to the position indicated in the Ephemeris.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
		h m s	m s	m s	' "
1.	Comet, South....	9 31 16	33 22		
	* a, North.....	31 45	33 31	-0 19.5	-18 4
2.	Comet, South....	9 35 4	37 13		
	* a, North.....	35 38	37 24	-0 22.9	-17 13
3.	Comet, South....	9 39 1	41 9		
	* a, North.....	39 36.5	41 15	-0 21.1	-18 29
4.	Comet, South....	9 43 28	45 36.5		
	* a, North.....	44 7	45 43.5	-0 23.3	-18 32
5.	Comet, South....	9 49 8	50 51		
	* a, North.....	49 16.5	51 26.5	-0 22.1	-17 14
6.	* b, North.....	9 55 44	57 47	+5 23.3	
	* c, North.....	10 0 49	1 39	+0 54.0	
	Comet.....	1 1	3 15		
	* d, South.....	3 45.5	5 34	-2 32.0	
	* e, North.....	5 0.5	6 49	-3 47.4	

The comet appeared as an ill-defined nebulous mass, several minutes in diameter, brighter towards the middle. It seemed as bright as when I saw it on the meridian at Edinburgh, on November 22nd 1828, with an achromatic telescope of thirty inches focal length and two inches aperture; but not nearly so bright as it appeared in the beginning of December of the same year.

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
		h m s	° ' "
a.....	7	3 43 58.8	-12 28 49
b (π Eridani)....	5	3 38 11.4	12 38 6
c.....	8	3 42 39.2	12 30 43
d.....	8	3 46 5.8	12 57 9
e.....	7	3 47 21.6	12 35 49

June 3rd.—The times are reckoned according to the chronometer, French, No. 975, which was gaining 13.4 seconds per diem on mean solar time: 9^h 27^m 15^s of the chronometer corresponded to 17^h 4^m 55^s mean time.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
1. {	* <i>f</i> , South	^h ^m ^s 9 21 52	^m ^s 23 13.5	^m ^s +0 23.3	+21 53
	Comet, North....	21 54	23 57		
2. {	* <i>f</i> , South	9 26 14.5	27 42.5	+0 25.9	+22 18
	Comet, North....	26 25	28 23		
3. {	* <i>f</i> , South	9 30 15	31 48	+0 24.8	+21 16
	Comet, North....	30 25.5	32 26		

The sky was hazy, and the comet faint. Afterwards clouds came on.

Apparent place of the star.

Star.	Magni- tude.	R.	Declination.
<i>f</i>	7.8	^h ^m ^s 3 39 7.9	-15 0 21

June 4th.—The times are reckoned by the assistant clock, which was losing 4.7 seconds in the hour on sidereal time: 0^h 17^m 0^s of the clock corresponded to 21^h 55^m 58^s sidereal time.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
1. {	* <i>g</i> , North	^h ^m ^s 0 26 39.5	^m ^s 22 1.5	^m ^s +0 37.3	- 7 50
	Comet, North....	26 52	29 4		
	* <i>h</i> , South	29 34	31 8.5	-2 23.3	+18 34
2. {	* <i>g</i> , North	0 33 35	34 43	+0 38.3	- 8 0
	Comet, North....	33 43	35 52		
	* <i>h</i> , South	36 18	38 2	-2 22.7	+18 20
3. {	* <i>g</i> , North	0 39 53.7	40 43	+0 37.4	- 8 17
	Comet, North....	39 53	41 59		
	* <i>h</i> , South	42 24	44 15.5	-2 23.9	+18 1
4. {	* <i>g</i> , North	0 46 6	47 35.5	+0 36.1	- 7 52
	Comet, North....	46 20	48 34		
	* <i>h</i> , South	49 6	50 34.5	-2 23.4	+18 26
5. {	* <i>g</i> , North	0 52 2.5	53 18	+0 36.6	- 8 24
	Comet, North....	52 11	54 23		
	* <i>h</i> , South	54 52	56 31	-2 24.6	+18 0
6. {	Comet, North....	1 1 28	3 39		
	* <i>i</i> , North	1 38	3 36.2	-0 3.8	- 3 3
7. {	* <i>g</i>	1 5 3	6 16	+0 33.4	-11 7
	Comet, North....	5 4	7 22		
	* <i>i</i>	5 18	7 22	-0 7.2	- 4 44

The comet had nearly the same appearance as on the 2nd.

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
		^h ^m ^s	[°] ['] ^{''}
<i>g</i>	8	3 34 29·4	—16 30 20
<i>h</i>	8.9	3 37 29·8	16 56 40
<i>i</i>	9	3 35 9·4	16 37 2

June 5th.—The times are reckoned by the assistant clock, which was losing 4·8 seconds in the hour on sidereal time: 1^h 4^m 0^s of the clock corresponded to 22^h 47^m 43^s·5 sidereal time.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
		^h ^m ^s	^m ^s	^m ^s	
1. {	* <i>k</i> , North	0 21 42	23 14	+1 0·0	—17 13
	Comet, South....	22 19	24 37		
2. {	* <i>k</i> , North	0 26 3	27 28·5	+1 0·8	—19 0
	Comet, South....	26 39	28 54		
3. {	* <i>k</i> , North	0 30 24·5	31 41	+0 58·2	—18 32
	Comet, South....	30 52	33 10		
4. {	* <i>l</i> , South	0 35 43	37 18	+1 50·1	+22 40
	Comet, North....	37 23	39 18		
5. {	* <i>l</i> , South	0 40 29	42 12	+1 50·5	+22 32
	Comet, North....	42 16	44 6		
6. {	* <i>l</i> , South	0 46 18	48 8·5	+1 49·2	+22 28
	Comet, North....	48 11	49 54		
7. {	* <i>l</i> , South	0 52 50·5	54 22	+1 49·3	+22 20
	Comet, North....	54 26	56 25		

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
		^h ^m ^s	[°] ['] ^{''}
<i>k</i>	8	3 29 32·0	—18 26 7
<i>l</i>	8	3 28 37·2	19 6 34

On June 6th and 7th the weather prevented any observations being made.

June 8th.—The times are reckoned by the assistant clock, which was losing 2·4 seconds in the hour on sidereal time: 0^h 23^m 0^s of the clock corresponded to 21^h 38^m 9^s·2 sidereal time.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
1.	* <i>m</i> , North.....	h m s 0 24 53	m s 25 45	+ 2 36.3	—30 9
	Comet, South....	27 15	28 35		
	* <i>n</i> , North.....	28 52	31 12.5	— 2 7.1	—20 3
2.	* <i>m</i> , North.....	0 32 38.5	33 23.5	+ 2 39.3	—31 19
	Comet, South....	35 7	36 13		
	* <i>n</i> , North.....	36 35	38 53.5	— 2 4.0	—21 31
3.	Comet, South....	0 48 18	50 28		
	* <i>n</i> , North.....	50 59	52 6.3	— 2 9.6	—23 24
4.	Comet, South....	0 55 28	57 25		
	* <i>n</i> , North.....	57 58	59 19.5	— 2 12.1	—24 40
	* <i>o</i> , North.....	1 5 38	8 6.5	—10 25.9	
5.	Comet.....	1 11 24	13 47		
	* <i>o</i>	22 0	24 13	—10 31.3	

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
<i>m</i>	7	h m s 3 12 14.5	—24 44 10
<i>n</i>	7.8	3 16 57.6	24 54 3
<i>o</i>	7	3 25 11.4	25 11 26

The comet was not again visible till the 23rd, owing partly to the weather, and partly to the moonlight, which obliterated the light of the comet even when the sky was clear.

June 23rd.—The times are reckoned by the assistant clock, which was losing 5.5 seconds in the hour on sidereal time: 1^h 53^m 0^s of the clock corresponded to 1^h 6^m 8^s.5 sidereal time.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
1.	Comet, South....	h m s 0 18 25	m s 21 15	m s	' "
	* <i>p</i> , South.....	23 34.5	27 14	— 5 34.0	— 3 27
	* <i>q</i> , South.....	26 4	29 40.5	— 8 2.3	— 3 10
	* <i>r</i> , North.....	28 34	32 43	—10 48.8	—17 58
2.	Comet, South....	0 39 40	42 20		
	* <i>p</i> , South.....	44 36.5	48 35	— 5 35.5	— 6 10
	* <i>q</i> , South.....	47 7	51 4.5	— 8 5.7	— 6 1
	* <i>r</i> , North.....	49 54	53 48	—10 51.2	—20 53

The comet was much fainter than when last observed. It was not visible in the telescopes of the meridian instruments, the twilight having commenced.

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
		^h ^m ^s	[°] ['] ^{''}
<i>p</i>	7	0 26 13.9	-59 7 26
<i>q</i>	7.8	0 28 42.9	59 7 48
<i>r</i>	6.7	0 31 29.3	58 53 8

On June 24th and 25th the weather was unfavourable.

June 26th.—The times are reckoned by the assistant clock, which was losing 5.7 seconds in the hour on sidereal time: 1^h 31^m 0^s of the clock corresponded to 0^h 56^m 59^s sidereal time.

	Ingress.	Egress.	Comet minus Star.	
			R.	Declination.
	^h ^m ^s	^m ^s	^m ^s	['] ^{''}
* <i>s</i> , North.....	0 23 30	27 35	+3 17.6	- 3 27
* <i>t</i> , North.....	23 33	28 21	+2 53.1	
* <i>u</i> , South.....	24 27	28 15	+2 29.0	+16 13
Comet, North ..	26 35	31 5		

The comet was fainter than on the 23rd. It was not seen in the transit telescope as it passed the meridian. It is probable that a mistake was committed in setting the telescope.

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
		^h ^m ^s	[°] ['] ^{''}
<i>s</i>	7	23 12 29.1	-62 12 36
<i>t</i>	7	23 12 49.0	-62 20 22
<i>u</i>	7	23 13 14.1	-62 32 46

June 27th.—This day's observations are reckoned by a clock of MOLYNEUX, losing 10.6 seconds in the day on mean solar time. At 16^h 30^m by the clock it was 3^m 28^s.6 slow of mean time.

The following observation of the comet's passage through the field of view

of the transit telescope was made by the assistant astronomer, Lieutenant W. MEADOWS, R.N. Not the slightest illumination could be permitted: the whole room had to be darkened to allow the comet being seen. The wires of the transit instrument were completely invisible.

The comet was not perceived till it had entered the field of view.

At 16 ^h 26 ^m 12 ^s it was estimated that the comet was in the middle of the field of view.

At 16 30 18 the preceding edge of the comet passed out of the field.

At 16 30 30 the whole was gone.

The telescope was set to 62° 48' of south declination, and the comet passed along the middle of the field.

The correction of the transit instrument for its deviation from the meridian, at the comet's parallel, was 1.1 second *additive*; and the time employed by an equatorial star in passing from the middle wire till its disappearance from the field is 126.9 seconds of sidereal time, for the eye-glass which was used.

The comet was not seen in the telescope of the mural circle.

		Ingress.	Egress.	Comet minus Star.	
				R.	Declination.
1.	* y.....	16 43 39	48 32	+5 2.6	" "
	Comet	49 2	53 12		
2.	* w, North.....	17 4 5	6 34	+7 24.4	-22 3
	* z, North.....	3 42	8 29	+6 38.3	-11 20
	* y, South.....	5 38	10 22	+4 43.5	-2 43
	Comet, South ..	10 32	14 53		

The comet was very faint, and it was very difficult to estimate its centre.

Apparent places of the stars.

Stars.	Magni- tude.	R.	Declination.
w	7.8	^h ^m ^s 22 46 15.0	-62 33 47
z.....	7.9	22 47 1.6	62 44 55
y.....	7.8	22 48 55.3	62 52 37

June 28th.—At the comet's meridian transit, it was seen very faintly in the

and e No. 222 of the Constellation Eridanus in BODE's Catalogue; f is in BESSEL's Zone No. 262, 7.8 magnitude, $t = 3^h 39^m 33^s.98$; $\delta = -14^\circ 59' 3''.6$; g, h, i, n and o are in the Histoire Céleste Française,

	Magn.	Middle wire.			Zenith distance.
		^{h}	^{m}	^{s}	
g , page 478 . . .	8 . . .	3	33	15.5 . . .	$65^\circ 23' 27''$
h , ——— 557 . . .	8.9 . . .	3	36	16.3 . . .	$65^\circ 49' 30''$
i , ——— — . . .	9 . . .	3	33	56 . . .	$65^\circ 30' 7''$
n , ——— 563 . . .	7.8 . . .	3	15	53.0 . . .	$73^\circ 47' 4''$
o , ——— — . . .	7 . . .	3	24	7.4 . . .	$74^\circ 4' 5''$

r is in La Caille's Coelum Australe Stelliferum, Zone XII. 31st of August 1751, *in parte inferiore reticulì*, 6.7 magnit.

$\left. \begin{array}{l} ^h \quad ^m \quad ^s \\ 0 \quad 22 \quad 11 \\ 30 \quad 33 \end{array} \right\}$

In computing the differences of right ascension and declination betwixt the comet and stars, allowance has been made for the comet's motion throughout, and for the effect of refraction for the observations preceding June 23rd. For the observations of that and subsequent days, the effect of refraction has been disregarded, as insensible. The sign + denotes the comet to be more advanced in right ascension than the star, or to the northward of it; the sign — the contrary.

From the observations, the following positions of the comet, cleared of refraction and parallax, have been computed. They are therefore the apparent geocentric places of the comet.

Nò.	Date.	Mean time.	R.	Declination.
	1832.	$^h \quad ^m \quad ^s$	$^h \quad ^m \quad ^s$	
1	June 2	17 18 31		$-12^\circ 46' 57''$
2	"	17 22 6	3 43 35.0	
3	3	17 4 55	3 39 31.1	$14^\circ 38' 46''$
4	4	17 23 41	3 35 4.2	$16^\circ 39' 19''$
5	5	17 23 52	3 30 27.5	$18^\circ 44' 28''$
6	8	16 47 29		$25^\circ 16' 40''$
7	"	16 53 32	3 14 46.0	
8	23	17 45 4	0 20 38.7	$59^\circ 12' 11''$
9	26	17 33 36	23 15 44.6	$62^\circ 16' 4''$
10	27	16 29 21	22 54 14.0	
11	"	17 5 24	22 53 49.2	
12	"	17 16 11		$62^\circ 55' 34''$
13	28	16 3 56	22 32 41.8	

The positions Nos. 10 and 13 are deduced from the observations of the egress of the comet's centre from the field of the transit telescope; the others, from the observations with the circular micrometer.

*Observatory, Cape of Good Hope,
March 8, 1833.*

XXIV.—*On the development of the disturbing Function, upon which depend the inequalities of the motions of the Planets, caused by their mutual attraction.* By JAMES IVORY, K.H., M.A., F.R.S., *Instit. Reg. Sc. Paris. Corresp. et Reg. Sc. Götting. Corresp.*

Received May 30,—Read June 20, 1833.

THE perturbations of the planets caused by their mutual attraction depend chiefly upon one algebraic expression, from the development of which all the inequalities of their motions are derived. This function is very complicated, and requires much labour and many tedious operations to expand it in a series of parts which can be separately computed according to the occasions of the astronomer. The progress of physical astronomy has undoubtedly been retarded by the excessive length and irksomeness attending the arithmetical calculation of the inequalities. On this subject astronomers generally and continually complain; and that their complaints are well founded, is very aptly illustrated by a paper contained in the last year's Transactions of this Society.

The disturbing function is usually expanded in parts arranged according to the powers and products of the excentricities and the inclinations of the orbits to the ecliptic; and, as these elements are always small, the resulting series decreases in every case with great rapidity. No difficulty would therefore be found in this research, if an inequality depended solely on the quantity of the coefficient of its argument in the expanded function; because the terms of the series decrease so fast, that all of them, except those of the first order, or, at most, those of the first and second orders, might be safely neglected, as producing no sensible variation in the planet's motion. But the magnitude of an inequality depends upon the length of its period, as well as upon the coefficient of its argument. When the former embraces a course of many years, the latter, although almost evanescent in the differential equation, acquires a great multiplier in the process of integration, and thus comes to have a sensible effect on the place of the planet. Such is the origin of some of the most remarkable

of the planetary irregularities, and in particular, of the great equations in the mean motions of Jupiter and Saturn, the discovery of which does so much honour to the sagacity of LAPLACE. It is not, therefore, enough to calculate the terms of the first order, or of the first and second orders, in the expansion of the disturbing function. This is already done in most of the books that treat of physical astronomy with all the care and fulness which the importance of the subject demands, leaving little room for further improvement. In the present state of the theory of the planetary motions, it is requisite that the astronomer have it in his power to compute any term in the expansion of the disturbing function below the sixth order; since it has been found that there are inequalities depending upon terms of the fifth order, which have a sensible effect on the motions of some of the planets.

A research that has for its object the lessening of the difficulty attending the expansion of the disturbing function, and the bringing of that expression more under the power of the astronomer, is one of considerable interest, and of some moment to the progress of physical astronomy. But the question is not to exhibit separately every individual argument with its coefficient, which would be of little utility in practice, since, although their number be infinite, very few of them are of any account in computing the place of a planet. The end to be aimed at, is to give the function such a form that the astronomer may have it in his power to select any inequality he may wish to examine, and to compute the coefficient of its argument by an arithmetical process of moderate length. The present Paper is an attempt of this kind. The investigation comprehends every argument not passing the fifth order; but, as the formulas are regular, the method may be extended indefinitely to any order.

1. Let x, y, z , represent the rectangular coordinates of the disturbed planet, z being perpendicular to a fixed plane passing through the sun's centre, at which point the origin of the coordinates is placed: in like manner let x', y', z' be the coordinates of the disturbing planet; and put m' for the proportion of the mass of this planet to the sum of the masses of the sun and the disturbed planet; then, R denoting the disturbing function, we shall have,

$$R = m'. \left\{ \frac{1}{\sqrt{(x' - x)^2 + (y' - y)^2 + (z' - z)^2}} - \frac{xx' + yy' + zz'}{(x'^2 + y'^2 + z'^2)^{\frac{3}{2}}} \right\}.$$

If r and r' denote the distances of the disturbed and disturbing planets from

the sun's centre ; ω , their angular distance seen at the same point ; and ρ , their rectilinear distance from one another, then,

$$\rho = \sqrt{r^2 - 2rr' \cos \omega + r'^2}$$

$$\frac{R}{m'} = \frac{1}{\rho} - \frac{r \cos \omega}{r'^3}.$$

It appears, therefore, that the function to be expanded consists of two parts, of which $\frac{1}{\rho}$, the reciprocal of the distance of the two planets, is common to the disturbing functions of both ; but this is not the case with the other part, in which r and r' do not enter alike. For this reason it will contribute to distinctness to expand the two parts separately. But, previously, it is necessary to express $\cos \omega$ in terms of the angular motions of the planets in their respective orbits.

If ν represent the angular distance of the disturbed planet in its orbit from a fixed origin, and P the place of the node, that is, of the intersection of the orbit with the immoveable plane of xy , P being reckoned in the same plane and from the same origin as ν , then $\nu - P$ will be the angular distance of the planet from the node. Further, if A be the celestial arc between the node and the intersection of the orbits of the two planets, the distance of the planet from the same intersection will be equal to

$$\nu - P - A.$$

If the foregoing symbols be accented and transferred with like significations to the disturbing planet, the celestial arc between that planet and the intersection of the orbits will be equal to

$$\nu' - P' - A'.$$

Now $\nu - P - A$ and $\nu' - P' - A'$ are two sides of a triangle of which the arc ω is the third side ; wherefore if I be the inclination of the two orbits, we shall have

$$\begin{aligned} \cos \omega &= \cos (\nu - P - A) \cos (\nu' - P' - A') \\ &\quad + \cos I \sin (\nu - P - A) \sin (\nu' - P' - A'), \end{aligned}$$

or, which is the same thing,

$$\begin{aligned} \cos \omega &= \cos^2 \frac{1}{2} I \cdot \cos (\nu - \nu' - P + P' - A + A') \\ &\quad + \sin^2 \frac{1}{2} I \cdot \cos (\nu + \nu' - P - P' - A - A'). \end{aligned}$$

Let N be the place of the node of the disturbed planet reckoned in the immoveable plane of xy , and i the inclination of the orbit to the same plane: then, if ν represent the longitude of the intersection of the orbits of the two planets, A will be the hypotenuse of a right-angled triangle, of which i is one angle, and $\nu - N$ the side adjacent to i ; wherefore

$$\tan A = \frac{\tan(\nu - N)}{\cos i};$$

and, by the usual methods,

$$A = \nu - N + \tan^2 \frac{i}{2} \sin 2(\nu - N) + \frac{1}{2} \tan^2 \frac{i}{2} \sin 4(\nu - N), \&c.;$$

and if we put

$$\xi = \tan^2 \frac{i}{2} \sin 2(\nu - N) + \frac{1}{2} \tan^2 \frac{i}{2} \sin 4(\nu - N), \&c.,$$

we shall have

$$P + A = \nu + P - N + \xi.$$

Let $[P - N]$ be the value of $P - N$ at some given epoch: then the differentials of N and P being dN and $\cos i \cdot dN$, we shall have generally,

$$P - N = [P - N] - \int dN + \int \cos i \cdot dN = [P - N] - 2 \int \sin^2 \frac{i}{2} dN,$$

the integral being taken for the time elapsed from the epoch. It thus appears that $P - N$ may be considered as an invariable arc, or as one subject to an almost insensible secular equation. In order to abridge expressions, let us now put

$$\alpha = [P - N] - 2 \int \sin^2 \frac{i}{2} dN + \xi;$$

then

$$\nu - P - A = \nu - \alpha - \nu.$$

If the symbols which stand for the elements of the disturbed planet be assumed, when accented, to represent the like elements of the disturbing planet, we shall have similarly,

$$\alpha' = [P' - N'] - 2 \int \sin^2 \frac{i'}{2} dN' + \xi',$$

$$\nu' - P' - A' = \nu' - \alpha' - \nu.$$

The value of $\cos \omega$ will now be thus expressed,

$$\begin{aligned}\cos \omega &= \cos^2 \frac{1}{2} I \cdot \cos (\nu - \nu' - \alpha + \alpha') \\ &+ \sin^2 \frac{1}{2} I \cdot \cos (\nu + \nu' - \alpha - \alpha' - 2 \nu).\end{aligned}$$

It remains to determine I , the inclination of the orbits, and ν , the longitude of their intersection. Now I is the vertical angle of a triangle of which $N - N'$ is the base, and i and i' the adjacent angles, one being interior and the other exterior to the triangle: wherefore

$$\cos I = \cos i \cos i' + \sin i \sin i' \cos (N - N').$$

In the same triangle, a perpendicular being let fall upon the base from the vertical angle, $\nu - N$ and $\nu - N'$ are the arcs between the perpendicular and the extremities of the base; and hence,

$$\cot \left(\nu - \frac{N + N'}{2} \right) = \frac{\sin (i - i')}{\sin (i + i')} \cdot \cot \frac{N - N'}{2}.$$

In the method here followed, the expression of $\cos \omega$ is as simple and as little troublesome in calculation, as it would be if one of the orbits were adopted for the immoveable plane.

2. Let ζ , ϵ , e , ϖ represent the mean motion, the epoch, the excentricity, and the place of the perihelion, of the disturbed planet at the time for which we are computing: if this time be near the epoch for which the elements have been assigned, the values at the epoch may be taken as the true values; and if a great interval has elapsed, the values at the epoch may be corrected by their secular equations. Further, put μ for the mean anomaly, σ for the equation of the centre, a for the mean distance, and $a(1 - s)$ for the radius vector: then,

$$\begin{aligned}\nu &= \zeta + \epsilon + \sigma, \\ \mu &= \zeta + \epsilon - \varpi, \\ \gamma &= a(1 - s),\end{aligned}$$

And the values of σ and s , found by the solution of KEPLER'S problem, are expressed by the usual series, viz.

$$\begin{aligned}
\sigma &= e \cdot 2 \sin \mu & s &= e \cos \mu \\
&+ e^2 \cdot \frac{5 \sin 2\mu}{4} & &+ e^2 \cdot \frac{\cos 2\mu - 1}{2} \\
&+ e^3 \cdot \frac{13 \sin 3\mu - 3 \sin \mu}{12} & &+ e^3 \cdot \frac{3 \cos 3\mu - 3 \cos \mu}{8} \\
&+ e^4 \cdot \frac{103 \sin 4\mu - 44 \sin 2\mu}{96} & &+ e^4 \cdot \frac{\cos 4\mu - \cos 2\mu}{3} \\
&+ e^5 \cdot \frac{1097 \sin 5\mu - 645 \sin 3\mu + 50 \sin \mu}{960} & &+ e^5 \cdot \frac{125 \cos 5\mu - 135 \cos 3\mu + 10 \cos \mu}{384}.
\end{aligned}$$

Using always the same symbols which stand for the elements of the disturbed planet, when accented, to represent the like elements of the disturbing planet, and introducing the new characters ϕ and ϕ' in order to shorten expressions, we shall have,

$$\begin{aligned}
\nu - \alpha &= \zeta + s - \alpha + \sigma = \phi + \sigma \\
\nu' - \alpha' &= \zeta' + s' - \alpha' + \sigma' = \phi' + \sigma'.
\end{aligned}$$

If these values, as well the values of r and r' , be substituted in that part of the disturbing function which is more easily dealt with, we shall obtain,

$$\begin{aligned}
\frac{r \cos \omega}{r'^3} &= \frac{a}{a'^3} \cdot \left\{ \cos^2 \frac{1}{2} I \cdot \cos (\phi - \phi' + \sigma - \sigma') \cdot \frac{1-s}{(1-s')^3} \right. \\
&\quad \left. + \sin^2 \frac{1}{2} I \cdot \cos (\phi + \phi' + \sigma + \sigma' - 2\nu) \cdot \frac{1-s}{(1-s')^3} \right\};
\end{aligned}$$

or,

$$\begin{aligned}
\frac{r \cos \omega}{r'^3} &= \frac{a}{a'^3} \cdot \left\{ \cos^2 \frac{1}{2} I \cdot \cos (\phi - \phi') \cdot \frac{(1-s) \cos (\sigma - \sigma')}{(1-s')^3} \right. \\
&\quad - \cos^2 \frac{1}{2} I \cdot \sin (\phi - \phi') \cdot \frac{(1-s) \sin (\sigma - \sigma')}{(1-s')^3} \\
&\quad + \sin^2 \frac{1}{2} I \cdot \cos (\phi + \phi' - 2\nu) \cdot \frac{(1-s) \cos (\sigma + \sigma')}{(1-s')^3} \\
&\quad \left. - \sin^2 \frac{1}{2} I \cdot \sin (\phi + \phi' - 2\nu) \cdot \frac{(1-s) \sin (\sigma + \sigma')}{(1-s')^3} \right\}.
\end{aligned}$$

The inspecting of this formula is sufficient to show that the expansion of the part multiplied by $\sin^2 \frac{1}{2} I$ is deducible without calculation from the expansion of the other part. For, as σ' is a series of the sines, and s' a series of the cosines, of the multiples of μ' , the former will change its sign with μ' , while the latter

will not vary: wherefore the expansion of the part multiplied by $\sin^2 \frac{1}{2} I$ will be obtained from the expansion of the other part, merely by making μ' negative, and writing $\phi + \phi' - 2\tau$ in place of $\phi - \phi'$ in all the arguments.

We have therefore only to expand the two first lines of the expression, for which purpose they may be thus written :

$$\begin{aligned} & \cos(\phi - \phi') \cdot \left\{ (1-s) \cos \sigma \times \frac{\cos \sigma'}{(1-s')^3} + (1-s) \sin \sigma + \frac{(\sin \sigma')}{(1-s')^3} \right\} \\ & + \sin(\phi - \phi') \cdot \left\{ -(1-s) \sin \sigma \times \frac{\cos \sigma'}{(1-s')^3} + (1-s) \cos \sigma \times \frac{(\sin \sigma')}{(1-s')^3} \right\} \end{aligned}$$

Neglecting quantities above the fifth order with respect to the excentricities, we have,

$$(1-s) \cos \sigma = 1 - s - \frac{\sigma^2}{2} + \frac{s\sigma^2}{2} + \frac{\sigma^4}{24} - \frac{s\sigma^4}{24},$$

$$(1-s) \sin \sigma = \sigma - s\sigma - \frac{\sigma^3}{6} + \frac{s\sigma^3}{6} + \frac{\sigma^5}{120};$$

And, if we assume,

$$(1-s) \cos \sigma = A^{(0)} + A^{(1)} e \cos \mu + A^{(2)} e^2 \cos 2\mu \dots + A^{(5)} e^5 \cos 5\mu,$$

$$(1-s) \sin \sigma = B^{(1)} e \sin \mu + B^{(2)} e^2 \sin 2\mu \dots B^{(5)} e^5 \sin 5\mu;$$

we shall readily find,

$$A^{(0)} = 1 - \frac{e^2}{2} - \frac{e^4}{64}$$

$$B^{(1)} = 2 - \frac{3}{8} e^2 + \frac{5}{96} e^4$$

$$A^{(1)} = -1 - \frac{3}{8} e^2 + \frac{5}{96} e^4$$

$$B^{(2)} = \frac{1}{4} - \frac{5}{12} e^2$$

$$A^{(2)} = \frac{1}{2} - \frac{e^2}{3}$$

$$B^{(3)} = \frac{7}{24} - \frac{41}{96} e^2$$

$$A^{(3)} = \frac{3}{8} - \frac{13}{32} e^2$$

$$B^{(4)} = \frac{29}{64}$$

$$A^{(4)} = \frac{67}{129}$$

$$B^{(5)} = \frac{77}{240}$$

$$A^{(5)} = \frac{17}{48}$$

And, by proceeding similarly,

$$\frac{\cos \sigma'}{(1-s')^2} = a^{(0)} + a^{(1)} \cdot e' \cos \mu' + a^{(2)} \cdot e'^2 \cos 2\mu' \dots + a^{(5)} \cdot e'^5 \cos 5\mu'$$

$$\frac{\sin \sigma'}{(1-s')^2} = b^{(1)} \cdot e' \sin \mu' + b^{(2)} \cdot e'^2 \sin 2\mu' \dots + b^{(5)} \cdot e'^5 \sin 5\mu'$$

$$a^{(0)} = 1 - \frac{e'^2}{2} - \frac{e'^4}{24}$$

$$b^{(1)} = 2 - \frac{3}{2} e'^2 + \frac{5}{24} e'^4$$

$$a^{(1)} = 2 - \frac{3}{2} e'^2 + \frac{5}{24} e'^4$$

$$b^{(2)} = \frac{13}{4} - \frac{41}{12} e'^2$$

$$a^{(2)} = \frac{7}{2} - \frac{10}{3} e'^2$$

$$b^{(3)} = \frac{31}{6} - \frac{161}{24} e'^2$$

$$a^{(3)} = \frac{11}{2} - \frac{53}{8} e'^2$$

$$b^{(4)} = \frac{761}{96}$$

$$a^{(4)} = \frac{1603}{192}$$

$$b^{(5)} = \frac{2827}{240}$$

$$a^{(5)} = \frac{149}{12}$$

We can now assign any term of the expansion we are considering. Let i and i' be any two positive numbers, zero included, of which the sum does not exceed 5: the part of the expansion multiplied by $e' e'^{i'} \cos^2 \frac{1}{2} I$ will be,

$$\begin{aligned} & \cos(\varphi - \varphi') \cdot \left\{ A^{(i)} a^{(i')} \cos i\mu \cos i'\mu' + B^{(i)} b^{(i')} \sin i\mu \sin i'\mu' \right\} \\ & + \sin(\varphi - \varphi') \cdot \left\{ -B^{(i)} a^{(i')} \sin i\mu \cos i'\mu' + b^{(i')} A^{(i)} \sin i'\mu' \cos i\mu \right\} : \end{aligned}$$

and, by reduction,

$$\begin{aligned} & \left(\frac{A^{(i)} a^{(i')} + B^{(i)} b^{(i')}}{4} - \frac{B^{(i)} a^{(i')} + b^{(i')} A^{(i)}}{4} \right) \cdot \cos(\varphi - \varphi' - i\mu + i'\mu') \\ & + \left(\frac{A^{(i)} a^{(i')} + B^{(i)} b^{(i')}}{4} + \frac{B^{(i)} a^{(i')} + b^{(i')} A^{(i)}}{4} \right) \cdot \cos(\varphi - \varphi' + i\mu - i'\mu') \\ & + \left(\frac{A^{(i)} a^{(i')} - B^{(i)} b^{(i')}}{4} - \frac{B^{(i)} a^{(i')} - b^{(i')} A^{(i)}}{4} \right) \cdot \cos(\varphi - \varphi' - i\mu - i'\mu') \\ & + \left(\frac{A^{(i)} a^{(i')} - B^{(i)} b^{(i')}}{4} + \frac{B^{(i)} a^{(i')} - b^{(i')} A^{(i)}}{4} \right) \cdot \cos(\varphi - \varphi' + i\mu + i'\mu'). \end{aligned}$$

The other part of the expansion, that multiplied by $e^{(i)} e'^{(i')} \sin^2 \frac{1}{2} I$, will be different in no respect from the part just computed except in the arguments of the cosines, which must be changed according to the rule already laid down; so that, instead of the four cosines above, these which follow must be substituted respectively,

$$\begin{aligned} & \cos(\varphi + \varphi' - 2\nu - i\mu - i'\mu') \\ & \cos(\varphi + \varphi' - 2\nu + i\mu + i'\mu') \\ & \cos(\varphi + \varphi' - 2\nu - i\mu + i'\mu') \\ & \cos(\varphi + \varphi' - 2\nu + i\mu - i'\mu'). \end{aligned}$$

Every part of the expansion being comprehended in the formula, it follows that all the arguments will contain the mean motions of the planets, excepting the particular case when $i = 1, i' = 1$: for, in this case, $\varphi - \mu$ and $\varphi' - \mu'$ are independent of the mean motions; and the first cosines of the two parts multiplied by $e e'$ will be,

$$\begin{aligned} & \cos(\varpi - \varpi' - \alpha + \alpha') \\ & \cos(\varpi + \varpi' - 2\nu - \alpha - \alpha'). \end{aligned}$$

These cosines have the same coefficient, viz.

$$\frac{A^{(1)} a^{(1)} + B^{(1)} b^{(1)}}{4} - \frac{B^{(1)} a^{(1)} + A^{(1)} b^{(1)}}{4};$$

And this will be found equal to zero, when the values of the symbols are substituted*. It thus appears, as far as the calculation has been carried, that there are no terms in the expansion of $\frac{r \cos \omega}{r'^2}$ except such as contain the mean motions and are periodical.

3. We next proceed to the expansion of $\frac{1}{\rho}$, which is the more difficult part of the problem. The value of $\cos \omega$, already investigated, may be thus written,

$$\begin{aligned} & \cos \omega = \cos(\varphi - \varphi' + \sigma - \sigma') \\ & - \sin^2 \frac{1}{2} I \cdot \left\{ \cos(\varphi - \varphi' + \sigma - \sigma') - \cos(\varphi + \varphi' + \sigma + \sigma' - 2\nu) \right\}: \end{aligned}$$

* The coefficient is equal to zero, because $a^{(i)} = b^{(i)}$: and for the same reason the coefficient

$$\frac{A^{(1)} a^{(1)} - B^{(1)} b^{(1)}}{4} + \frac{B^{(1)} a^{(1)} - b^{(1)} A^{(1)}}{4}$$

is equal to zero.

wherefore,

$$\begin{aligned} D^2 &= r^2 + r'^2 - 2rr' \cos(\phi - \phi' + \sigma - \sigma'), \\ q &= \cos(\phi - \phi' + \sigma - \sigma') - \cos(\phi + \phi' + \sigma + \sigma' - 2\pi), \\ \rho^2 &= r^2 + r'^2 - 2rr' \cos \alpha = D^2 + 2 \sin^2 \frac{1}{2} I \cdot rr' q; \end{aligned}$$

consequently,

$$\frac{1}{\rho} = \frac{1}{D} - \sin^2 \frac{1}{2} I \cdot \frac{rr'}{D^3} q + \frac{1}{4} \sin^4 \frac{1}{2} I \cdot \frac{r^2 r'^2}{D^5} q^2;$$

and the three parts of $\frac{1}{\rho}$ must be expanded separately.

Expansion of $\frac{1}{D}$.

By substituting $a(1-s)$ and $a'(1-s')$ for r and r' , we get

$$\frac{1}{D} = \frac{1}{\sqrt{a^2(1-s)^2 + a'^2(1-s')^2 - 2aa'(1-s)(1-s') \cos(\phi - \phi' + \sigma - \sigma')}};$$

and it will be found that the following equation, in partial differentials, is true, viz.

$$\frac{1}{D} = \frac{d \cdot \frac{1}{D}}{ds} (1-s) + \frac{d \cdot \frac{1}{D}}{ds'} (1-s').$$

All the possible values of $\frac{1}{D}$ in this equation are comprehended in the formula,

$$\frac{1}{D} = G \times F;$$

provided F and G verify these equations,

$$G = \frac{dG}{ds} (1-s) + \frac{dG}{ds'} (1-s')$$

$$0 = \frac{dF}{ds} (1-s) + \frac{dF}{ds'} (1-s').$$

We may adopt for G any particular expression which verifies its proper equation; and then F will be determined by the nature of the quantity sought. Any function of $(1-s)$ and $(1-s')$ of -1 dimension will verify the equation for G ; and, taking the most simple case, $G = \frac{1}{1-s}$, we shall have

$$\frac{1}{D} = \frac{1}{1-s} \times F.$$

Now let

$$D_0 = \sqrt{a^2 + a'^2 - 2aa' \cos(\phi - \phi' + \sigma - \sigma')};$$

then first, if we suppose $s = 0, s' = 0$, we get

$$\frac{1}{D} = \frac{1}{D_0};$$

and again, if we suppose $s = s'$, the result will be,

$$\frac{1}{D} = \frac{1}{1-s} \cdot \frac{1}{D_0};$$

and thus we learn that

$$F = \frac{1}{D_0},$$

both when $s = 0, s' = 0$, and when $s = s'$. From its equation we know that F must be a function of no dimensions with respect to $(1-s)$ and $(1-s')$; and this condition, as well as what has been shown to take place on the two foregoing suppositions, will be fulfilled by making F a function of $\left(1 - \frac{1-s'}{1-s}\right) = \frac{s'-s}{1-s}$: wherefore the expression of $\frac{1}{D}$ will be as follows:

$$\frac{1}{D} = \frac{1}{1-s} \cdot f\left(\frac{s'-s}{1-s}\right),$$

f being the mark of a function which, in the present case, must be equal to $\frac{1}{D_0}$ when $\frac{s'-s}{1-s} = 0$.

Since s and s' are small quantities, the expression of $\frac{1}{D}$ may be expanded.

By neglecting quantities above the fifth order with respect to s and s' ,

$$\frac{1}{D} = \frac{B^{(0)}}{1-s} + B^{(1)} \cdot \frac{s'-s}{(1-s)^2} + B^{(2)} \cdot \frac{(s'-s)^2}{(1-s)^3} + \dots + B^{(5)} \cdot \frac{(s'-s)^5}{(1-s)^6}.$$

In this form it is obvious that all the coefficients may be readily found. For, by differentiating successively with respect to s' , and supposing $s = 0, s' = 0$, in all the results, we obtain,

$$B^{(0)} = \frac{1}{D_0}, B^{(1)} = \frac{d}{ds'} \frac{1}{D}, B^{(2)} = \frac{1}{1.2} \cdot \frac{d^2}{ds'^2} \frac{1}{D}, \&c.$$

But the expression is complicated; and in order to reduce it to a more ma-

nageable form, every separate term may be resolved into a series of the powers and products of s and s' : which being done, and the quantities of the same order classed together, we shall find,

$$\begin{aligned} \frac{1}{D} = & B^{(0)} + B^{(1)} \cdot s' + B^{(2)} s^2 + B^{(3)} s'^3 + \&c.; \\ & - (B^{(1)} - B^{(0)}) \cdot s - (B^{(2)} - B^{(1)}) \cdot 2 s s' - (B^{(3)} - B^{(2)}) \cdot 3 s'^2 s \\ & + (B^{(2)} - 2B^{(1)} + B^{(0)}) s^2 + (B^{(3)} - 2B^{(2)} + B^{(1)}) \cdot 3 s' s^2 \\ & - (B^{(3)} - 3B^{(2)} + 3B^{(1)} - B^{(0)}) \cdot s^3 \end{aligned}$$

Or, in the usual notation of finite differences,

$$\begin{aligned} \frac{1}{D} = & B^{(0)} + B^{(1)} \cdot s' + B^{(2)} \cdot s'^2 + B^{(3)} s'^3 + B^{(4)} \cdot s'^4 + \&c.; \\ & - \Delta B^{(0)} \cdot s - \Delta B^{(1)} \cdot 2 s s' - \Delta B^{(2)} \cdot 3 s'^2 s - \Delta B^{(3)} \cdot 4 s'^3 s \\ & + \Delta^2 B^{(0)} \cdot s^2 + \Delta^2 B^{(1)} \cdot 3 s' s^2 + \Delta^2 B^{(2)} \cdot 6 s'^2 s^2 \\ & - \Delta^3 B^{(0)} \cdot s^3 - \Delta^3 B^{(1)} \cdot 4 s' s^3 \\ & + \Delta^4 B^{(0)} \cdot s^4. \end{aligned}$$

The value of $\frac{1}{D}$ seems now to be reduced to its most simple form as far as s and s' are concerned. If it be observed that, in every term, the exponent of the power of s' is the same with the numeral affix of B , and the exponent of s the same with the index of Δ , it will appear that the whole expansion is comprehended in the formula,

$$\Delta^i B^{(i')} \cdot \beta s'^{i'} s^i,$$

β being the coefficient of $s'^i s^i$ in $(s' - s)^{i' + i}$, and i' , i , representing the several positive numbers, zero included, of which the sum $(i' + i)$ does not exceed 5, when the expansion is limited to quantities of the fifth order.

4. The values of the quantities $B^{(0)}$, $B^{(1)}$, &c., are next to be investigated. If, for the sake of abridging, we put,

$$Q = a^n (1 - s') - a a' (1 - s) \cos (\phi - \phi' + \sigma - \sigma'),$$

we shall get by repeated differentiations,

$$\frac{d}{ds} \frac{1}{D} = \frac{Q}{D^3},$$

$$\frac{1}{1 \cdot 2} \cdot \frac{d^2}{ds^2} \frac{1}{D} = \frac{1}{2} \cdot \frac{dQ}{ds} \cdot \frac{1}{D^3} + \frac{3}{2} \cdot \frac{Q^2}{D^5},$$

$$\frac{1}{1 \cdot 2 \cdot 3} \cdot \frac{d^3}{ds^3} \frac{1}{D} = \frac{3}{2} \cdot \frac{dQ}{ds} \cdot \frac{Q}{D^5} + \frac{5}{2} \cdot \frac{Q^3}{D^7},$$

$$\frac{1}{1 \cdot 2 \cdot 3 \cdot 4} \cdot \frac{d^4}{ds^4} \frac{1}{D} = \frac{3}{8} \cdot \left(\frac{dQ}{ds} \right)^2 \cdot \frac{1}{D^5} + \frac{15}{4} \cdot \frac{dQ}{ds} \cdot \frac{Q^2}{D^7} + \frac{35}{8} \cdot \frac{Q^4}{D^9},$$

$$\frac{1}{1 \cdot 2 \cdot 3 \cdot 4 \cdot 5} \cdot \frac{d^5}{ds^5} \frac{1}{D} = \frac{15}{8} \left(\frac{dQ}{ds} \right)^2 \cdot \frac{Q}{D^7} + \frac{35}{4} \cdot \frac{dQ}{ds} \cdot \frac{Q^3}{D^9} + \frac{63}{8} \cdot \frac{Q^5}{D^{11}}.$$

Now these expressions become equal to $B^{(1)}$, $B^{(2)}$, &c., when $s' = 0$, $s = 0$, that is, when

$$D = D_0,$$

$$Q = a'^2 - a a' \cos(\phi - \phi' + \epsilon - \epsilon') = \frac{D_0^2 + (a'^2 - a^2)}{2},$$

$$\frac{dQ}{ds} = -a'^2.$$

Let us now put

$$f = a'^2 - a^2, \quad h = \frac{a'^2 + a^2}{a'^2 - a^2};$$

then,

$$Q = \frac{D_0^2 + f}{2}, \quad \frac{dQ}{ds} = -f \times \frac{1+h}{2};$$

and, by substituting these values in the foregoing expressions, and reducing, we get

$$B^{(0)} = \frac{1}{D_0}$$

$$B^{(1)} = \frac{1}{2} \left(\frac{1}{D_0} + \frac{f}{D_0^3} \right)$$

$$B^{(2)} = \frac{3}{8} \left(\frac{1}{D_0} + \frac{f^2}{D_0^3} \right) + \frac{2-h}{4} \cdot \frac{f}{D_0^2},$$

$$B^{(3)} = \frac{5}{16} \left(\frac{1}{D_0} + \frac{f^2}{D_0^3} \right) + \frac{9-6h}{16} \left(\frac{f}{D_0^2} + \frac{f^3}{D_0^5} \right)$$

$$B^{(4)} = \frac{35}{128} \left(\frac{1}{D_0} + \frac{f^2}{D_0^3} \right) + \frac{20-15h}{32} \left(\frac{f}{D_0^2} + \frac{f^3}{D_0^5} \right) + \frac{6h^2-48h+51}{64} \cdot \frac{f^3}{D_0^5}$$

$$B^{(5)} = \frac{63}{256} \left(\frac{1}{D_0} + \frac{f^2}{D_0^3} \right) + \frac{175-140h}{256} \left(\frac{f}{D_0^2} + \frac{f^3}{D_0^5} \right) + \frac{30h^2-150h+135}{128} \cdot \left(\frac{f^3}{D_0^5} + \frac{f^5}{D_0^7} \right).$$

These quantities have been deduced from the differentials $\frac{d}{ds} \frac{1}{D}$, $\frac{1}{1.2} \cdot \frac{dd}{ds^2} \frac{1}{D}$,

&c. If the differentials $\frac{d}{ds} \frac{1}{D}$, $\frac{1}{1.2} \cdot \frac{dd}{ds^2} \frac{1}{D}$, &c., be used, the same results will be found, with this difference, that f and h , retaining the same numerical values, will both change their signs.

If we write ψ for $(\phi - \phi' + \sigma - \sigma')$ and differentiate the formula,

$$\frac{d}{d\psi} \frac{1}{D_0^n} = -n \cdot \frac{a a' \sin \psi}{D_0^{n+2}},$$

the result will be,

$$\frac{dd}{d\psi^2} \frac{1}{D_0^n} = -n \cdot \frac{a a' \cos \psi}{D_0^{n+2}} + n \cdot n + 2 \cdot \frac{a^2 a'^2 \sin^2 \psi}{D_0^{n+4}};$$

now,

$$a a' \cos \psi = \frac{a'^2 + a^2}{2} - \frac{D_0^2}{2},$$

$$a'^2 a^2 \sin^2 \psi = -\frac{D_0^4}{4} + \frac{a'^2 + a^2}{2} \cdot D_0^2 - \frac{(a'^2 - a^2)^2}{4};$$

wherefore,

$$\frac{dd}{d\psi^2} \frac{1}{D_0^n} = -\frac{n^2}{4} \cdot \frac{1}{D_0^n} + \frac{n \cdot n + 1}{2} \cdot \frac{a'^2 + a^2}{D_0^{n+2}} - \frac{n \cdot n + 2}{4} \cdot \frac{(a'^2 - a^2)^2}{D_0^{n+4}};$$

whence we deduce

$$\frac{f^2}{D_0^{n+4}} = -\frac{4}{n \cdot n+2} \cdot \frac{d d \frac{1}{D_0^n}}{d \psi^2} - \frac{n}{n+2} \cdot \frac{1}{D_0^n} + \frac{2(n+1)h}{n+2} \cdot \frac{f}{D_0^{n+2}}.$$

In this formula put n successively equal to 1, 3, 5, 7; then

$$\frac{f^2}{D_0^5} = -\frac{4}{3} \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} - \frac{1}{3} \cdot \frac{1}{D_0} + \frac{4h}{3} \cdot \frac{f}{D_0^3},$$

$$\frac{f^3}{D_0^7} = -\frac{4}{15} \cdot \frac{d d \frac{f}{D_0^3}}{d \psi^2} - \frac{3}{5} \cdot \frac{f}{D_0^3} + \frac{8h}{5} \cdot \frac{f^2}{D_0^5},$$

$$\frac{f^4}{D_0^9} = -\frac{4}{35} \cdot \frac{d d \frac{f^2}{D_0^5}}{d \psi^2} - \frac{5}{7} \cdot \frac{f^2}{D_0^5} + \frac{12h}{7} \cdot \frac{f^3}{D_0^7},$$

$$\frac{f^5}{D_0^{11}} = -\frac{4}{63} \cdot \frac{d d \frac{f^3}{D_0^7}}{d \psi^2} - \frac{7}{9} \cdot \frac{f^3}{D_0^7} + \frac{16h}{9} \cdot \frac{f^4}{D_0^9}.$$

By means of the two first of these last formulas, we can exterminate $\frac{f^2}{D_0^5}$ and $\frac{f^3}{D_0^7}$ from the values of $B^{(2)}$ and $B^{(3)}$; which being done, we shall find

$$B^{(2)} = \left(\frac{1}{4} \cdot \frac{1}{D_0} - \frac{1}{2} \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} \right) + \frac{2+h}{4} \cdot \frac{f}{D_0^3},$$

$$B^{(3)} = \left(\frac{3-h}{24} \cdot \frac{1}{D_0} - \frac{9+2h}{12} \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} \right) + \left(\frac{4h^2+9h+9}{24} \cdot \frac{f}{D_0^3} - \frac{1}{12} \cdot \frac{d d \frac{f}{D_0^3}}{d \psi^2} \right).$$

And, in like manner, by means of all the four formulas, we may exterminate $\frac{f^2}{D_0^5}$, $\frac{f^3}{D_0^7}$, $\frac{f^4}{D_0^9}$ and $\frac{f^5}{D_0^{11}}$, from the expressions of $B^{(2)}$ and $B^{(3)}$; and thus are obtained these values,

$$B^{(2)} = -\frac{3h^2+8h-7}{96} \cdot \frac{1}{D_0} + \frac{3h^2+8h^2+8h+6}{24} \cdot \frac{f}{D_0^3} \\ - \frac{12h^2+32h+77}{96} \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} - \frac{1}{6} \cdot \frac{d d \frac{f}{D_0^3}}{d \psi^2} - \frac{1}{32} \cdot \frac{d d \frac{f^2}{D_0^5}}{d \psi^2},$$

MDCCCXXXIII.

4 E

$$\begin{aligned}
B^{(5)} = & -\frac{24h^3 + 75h^2 + 92h - 55}{960} \cdot \frac{1}{D_0} + \frac{96h^4 + 300h^3 + 341h^2 + 200h + 159}{960} \cdot \frac{f}{D_0^3} \\
& - \frac{96h^3 + 300h^2 + 368h + 725}{960} \cdot \frac{dd \frac{1}{D_0^3}}{d\psi^2} - \frac{12h^3 + 221}{960} \cdot \frac{dd \frac{f}{D_0^3}}{d\psi^2} \\
& - \frac{25 - 4h}{320} \cdot \frac{dd \frac{f^2}{D_0^3}}{d\psi^2} - \frac{1}{64} \cdot \frac{dd \frac{f^3}{D_0^7}}{d\psi^2}.
\end{aligned}$$

If we take the second differentials relatively to ψ in the first two of the same

four formulas, we shall obtain these values of $\frac{dd \frac{f^2}{D_0^3}}{d\psi^2}$ and $\frac{dd \frac{f^3}{D_0^7}}{d\psi^2}$, viz.

$$\begin{aligned}
\frac{dd \frac{f^2}{D_0^3}}{d\psi^2} &= -\frac{4}{3} \cdot \frac{d^4 \frac{1}{D_0}}{d\psi^4} - \frac{1}{3} \cdot \frac{dd \frac{1}{D_0}}{d\psi^2} + \frac{4h}{3} \cdot \frac{dd \frac{f}{D_0^3}}{d\psi^2}, \\
\frac{dd \frac{f^3}{D_0^7}}{d\psi^2} &= -\frac{4}{15} \cdot \frac{d^4 \frac{f}{D_0^3}}{d\psi^4} - \frac{32h}{15} \cdot \frac{d^4 \frac{1}{D_0}}{d\psi^4} - \frac{8h}{15} \cdot \frac{dd \frac{1}{D_0}}{d\psi^2} + \frac{32h^2 - 9}{15} \cdot \frac{dd \frac{f}{D_0^3}}{d\psi^2}:
\end{aligned}$$

which being substituted, the expressions of $B^{(4)}$ and $B^{(5)}$ will be as follow:

$$\begin{aligned}
B^{(4)} = & -\frac{3h^3 + 8h - 7}{96} \cdot \frac{1}{D_0} - \frac{3h^3 + 8h + 19}{24} \cdot \frac{dd \frac{1}{D_0}}{d\psi^2} + \frac{1}{24} \cdot \frac{d^4 \frac{1}{D_0}}{d\psi^4} \\
& + \frac{3h^3 + 8h^2 + 8h + 6}{24} \cdot \frac{f}{D_0^3} - \frac{h + 4}{24} \cdot \frac{dd \frac{f}{D_0^3}}{d\psi^2}. \\
B^{(5)} = & \left\{ -\frac{24h^3 + 75h^2 + 92h - 55}{960} \cdot \frac{1}{D_0} - \frac{24h^3 + 75h^2 + 91h - 175}{240} \cdot \frac{dd \frac{1}{D_0}}{d\psi^2} \right. \\
& \left. + \frac{25 + 4h}{240} \cdot \frac{d^4 \frac{1}{D_0}}{d\psi^4} \right\} \\
& + \left\{ \frac{96h^4 + 300h^3 + 341h^2 + 200h + 159}{960} \cdot \frac{f}{D_0^3} - \frac{7h^3 + 25h + 53}{240} \cdot \frac{dd \frac{f}{D_0^3}}{d\psi^2} \right. \\
& \left. + \frac{1}{240} \cdot \frac{d^4 \frac{f}{D_0^3}}{d\psi^4} \right\}.
\end{aligned}$$

Thus the six quantities $B^{(0)}$, $B^{(1)}$, &c., are all expressed in terms of $\frac{1}{D_0}$

and $\frac{f}{D_0^3}$, and the second and fourth differentials of the same two quantities, the coefficients being of easy computation, and depending solely on the mean distances of the two planets.

5. The problem to be solved is, to expand $\frac{1}{D}$ in a series of terms arranged according to the cosines of the arc ψ , or $\phi - \phi' + \sigma - \sigma'$, and its successive multiples. Now as the quantities $\frac{1}{D_0}$ and $\frac{f}{D_0^3}$ and their differentials, are all susceptible of a like development, what is required will be accomplished merely by substituting in $B^{(0)}$, $B^{(1)}$, &c., the parts of $\frac{1}{D_0}$, $\frac{f}{D_0^3}$, and their differentials, multiplied by the cosine of the same multiple of ψ , instead of the quantities themselves. The coefficients of the cosines in the developments in question are functions of $\frac{a}{a'}$ or $\frac{a'}{a}$; and, for the sake of convergency, we must choose that one of the two fractions which is less than unit. Supposing that a' is greater than a , and that n represents any odd number, we have,

$$\frac{f^{\frac{n-1}{2}}}{D_0^n} = \frac{\left(1 - \frac{a^2}{a'^2}\right)^{\frac{n-1}{2}}}{a'} \times \frac{1}{\left\{1 + \frac{a^2}{a'^2} - 2 \frac{a}{a'} \cos \psi\right\}^{\frac{n}{2}}}.$$

Wherefore, assuming as usual,

$$\frac{1}{\left\{1 + \frac{a^2}{a'^2} - 2 \frac{a}{a'} \cos \psi\right\}^{\frac{n}{2}}} = \frac{1}{2} C_n^{(0)} + C_n^{(1)} \cos \psi + C_n^{(2)} \cos 2\psi \dots + C_n^{(k)} \cos k\psi \dots,$$

the part of $\frac{1}{D_0}$, and of its second and fourth differentials, which are multiplied by $\cos k\psi$, will be respectively,

$$\frac{\cos k\psi}{a'} \times C_1^{(k)}, \frac{\cos k\psi}{a'} \times -k^2 C_1^{(k)}, \frac{\cos k\psi}{a'} \times k^4 C_1^{(k)};$$

and the like parts of $\frac{f}{D_0^3}$ and its differentials, will be,

$$\frac{1 - \frac{a^2}{a'^2}}{a'} \times C_3^{(k)} \cos k\psi, \frac{1 - \frac{a^2}{a'^2}}{a'} \times -k^2 C_3^{(k)} \cos k\psi, \frac{1 - \frac{a^2}{a'^2}}{a'} \times k^4 C_3^{(k)} \cos k\psi.$$

It remains then to substitute these values in $B^{(0)}$, $B^{(1)}$, &c., in place of $\frac{1}{D_0}$, $\frac{f}{D_0}$, and their differentials: but, in order to obtain the formulas most convenient for calculation, it will be requisite to express the coefficient of the development of $\frac{f}{D_0}$ by means of those of the development of $\frac{1}{D_0}$.

If we write α for $\frac{a}{a'}$, and put

$$V = \sqrt{1 + \alpha^2 - 2\alpha \cos \psi},$$

we have this formula,

$$\frac{d \cdot \frac{1}{V}}{d\psi} = - \frac{\alpha \sin \psi}{V^3};$$

and if we substitute the expansions of $\frac{1}{V}$ and $\frac{1}{V^3}$, and equate the coefficients of $\sin k\psi$, the result will be

$$2k C_1^{(k)} = \alpha C_3^{(k-1)} - \alpha C_3^{(k+1)}.$$

We have likewise this identical expression,

$$\frac{1}{V} = \frac{V^3}{V^4} = \frac{1 + \alpha^2}{V^4} - \frac{2\alpha \cos \psi}{V^4};$$

and by substituting the expansions of $\frac{1}{V}$ and $\frac{1}{V^3}$, and equating the coefficients of $\cos k\psi$, we get

$$C_1^{(k)} = (1 + \alpha^2) C_3^{(k)} - \alpha C_3^{(k-1)} - \alpha C_3^{(k+1)}.$$

By combining the two formulas, we deduce

$$2\alpha C_3^{(k+1)} = (1 + \alpha^2) C_3^{(k)} - (2k + 1) C_1^{(k)}$$

$$2\alpha C_3^{(k-1)} = (1 + \alpha^2) C_3^{(k)} - (2k - 1) C_1^{(k)}.$$

Change k for $k - 1$ in the first of these formulas, and for $k + 1$ in the second, and the two following formulas will be obtained,

$$2\alpha C_3^{(k)} = (1 + \alpha^2) C_3^{(k-1)} - (2k - 1) C_1^{(k-1)}$$

$$2\alpha C_3^{(k)} = (1 + \alpha^2) C_3^{(k+1)} + (2k + 1) C_1^{(k+1)}.$$

By combining the four last formulas in different ways, different values of $C_3^{(k)}$ will be found, which may be used at pleasure, viz.

$$(1 - \alpha^2) C_3^{(k)} = (2k + 1) \cdot \left\{ \frac{1 + \alpha^2}{1 - \alpha^2} C_1^{(k)} - \frac{2\alpha}{1 - \alpha^2} \cdot C_1^{(k+1)} \right\}$$

$$(1 - \alpha^2) C_3^{(k)} = (2k - 1) \cdot \left\{ \frac{2\alpha}{1 - \alpha^2} C_1^{(k-1)} - \frac{1 + \alpha^2}{1 - \alpha^2} C_1^{(k)} \right\}$$

$$(1 - \alpha^2) C_3^{(k)} = \frac{4k^2 - 1}{4k} \cdot \frac{2\alpha}{1 - \alpha^2} \cdot (C_1^{k-1} - C_1^{k+1}).$$

In order to shorten expressions, and to bring the formulas to a form convenient for calculation, let

$$\alpha = \tan \frac{1}{2} \theta;$$

then,

$$\frac{1 + \alpha^2}{1 - \alpha^2} = h = \frac{1}{\cos \theta}, \quad \frac{2\alpha}{1 - \alpha^2} = \frac{\sin \theta}{\cos \theta} = h \sin \theta;$$

further, assume the new symbol $a^{(k)}$, the value of which may be calculated by any one of these formulas, viz.

$$a^{(k)} = (2k + 1) \cdot (C_1^k - \sin \theta C_1^{(k+1)}),$$

$$a^{(k)} = (2k - 1) \cdot (\sin \theta C_1^{(k-1)} - C_1^{(k)}),$$

$$a^{(k)} = \frac{4k^2 - 1}{4k} \cdot \sin \theta (C_1^{k-1} - C_1^{k+1});$$

then,

$$(1 - \alpha^2) C_3^{(k)} = h \cdot a^{(k)}.$$

Using this value, the parts of $\frac{f}{D_0^3}$ and its differentials, multiplied by $\cos k\psi$ will be

$$\frac{\cos k\psi}{a'} \times h a^{(k)}, \quad \frac{\cos k\psi}{a'} \times -h k^2 a^{(k)}, \quad \frac{\cos k\psi}{a'} \times h k^4 a^{(k)}.$$

These, as well as the like parts of $\frac{1}{D_0}$ and its differentials, must be substituted in $B^{(0)}$, $B^{(1)}$, &c. As there is no longer occasion to refer to any development but one, C^k may be written for $C_1^{(k)}$. In substituting we omit the common factor $\frac{\cos k\psi}{a'}$, and put

$$b_0^{(k)}, b_1^{(k)}, b_2^{(k)}, \dots, b_5^{(k)}$$

for the expressions into which

$$B^{(0)}, B^{(1)}, B^{(2)}, \dots, B^{(s)}$$

are changed, so that,

$$b_0^{(k)} = C^{(k)}$$

$$b_1^{(k)} = \frac{1}{2} C^{(k)} + \frac{h}{2} \cdot a^{(k)},$$

$$b_2^{(k)} = \left(\frac{1}{4} + \frac{1}{2} k^2 \right) C^{(k)} + \frac{h^2 + 2h}{4} \cdot a^{(k)},$$

$$b_3^{(k)} = \left(\frac{3-h}{24} + \frac{9+2h}{12} \cdot k^2 \right) \cdot C^{(k)} + \left(\frac{4h^3 + 9h^2 + 9h}{24} + \frac{h}{12} k^2 \right) \cdot a^{(k)},$$

$$b_4^{(k)} = \left(-\frac{3h^2 + 8h - 7}{96} + \frac{3h^2 + 8h + 19}{24} \cdot k^2 + \frac{k^4}{24} \right) \cdot C^{(k)}$$

$$+ \left(\frac{3h^4 + 8h^3 + 8h^2 + 6h}{24} + \frac{h^2 + 4h}{24} \cdot k^2 \right) \cdot a^{(k)},$$

$$b_5^{(k)} = \left(-\frac{24h^3 + 75h^2 + 92h - 55}{960} + \frac{24h^3 + 75h^2 + 91h + 175}{240} \cdot k^2 \right.$$

$$\left. + \frac{25 + 4h}{240} \cdot k^4 \right) \cdot C^{(k)}$$

$$+ \left(\frac{96h^5 + 300h^4 + 341h^3 + 200h^2 + 159h}{960} + \frac{7h^3 + 25h^2 + 53h}{240} k^2 + \frac{h k^4}{240} \right) \cdot a^{(k)}.$$

And, these symbols being established, the part of $\frac{1}{D}$ we are in search of, that is, the part multiplied by $\cos k(\varphi - \varphi' + \sigma - \sigma')$, will be thus expressed,

$$\frac{\cos k(\varphi - \varphi' + \sigma - \sigma')}{a'} \times$$

$$\left\{ \begin{aligned} & b_0^{(k)} + b_1^{(k)} \cdot s^1 + b_2^{(k)} \cdot s'^2 + b_3^{(k)} \cdot s'^3 + b_4^{(k)} \cdot s'^4 + b_5^{(k)} \cdot s'^5 \\ & - \Delta b_0^{(k)} \cdot s - \Delta b_1^{(k)} \cdot 2s^1 s - \Delta b_2^{(k)} \cdot 3s'^2 s - \Delta b_3^{(k)} \cdot 4s'^3 s - \Delta b_4^{(k)} \cdot 5s'^4 s \\ & + \Delta^2 b_0^{(k)} \cdot s^2 + \Delta^2 b_1^{(k)} \cdot 3s^1 s^2 + \Delta^2 b_2^{(k)} \cdot 6s'^2 s^2 + \Delta^2 b_3^{(k)} \cdot 10s'^3 s^2 \\ & - \Delta^3 b_0^{(k)} \cdot s^3 - \Delta^3 b_1^{(k)} \cdot 4s^1 s^3 - \Delta^3 b_2^{(k)} \cdot 10s'^2 s^3 \\ & + \Delta^4 b_0^{(k)} \cdot s^4 + \Delta^4 b_1^{(k)} \cdot 5s^1 s^4 \\ & - \Delta^5 b_0^{(k)} \cdot s^5. \end{aligned} \right.$$

By the foregoing analysis the problem is reduced to a series of terms comprehended in the formula,

$$\pm \Delta^i b_{\nu}^{(k)} \times \beta s'^{\nu} s^i \cos k(\varphi - \varphi' + \sigma - \sigma')$$

i' and i representing all positive numbers, zero included, of which the sum $i' + i$ does not exceed 5; β standing for the coefficient of $s'^{\nu} s^i$ in $(s' + s)^{\nu+i}$; and the upper or lower sign taking place according as the index of Δ is even or odd. Although all the coefficients are supposed to be deduced from six of them, for which alone direct expressions are given, it is nevertheless obvious that an independent formula may be found by which any proposed coefficient may be separately computed: namely, by substituting the values of $b_0^{(k)}$, $b_1^{(k)}$, &c., in the expressions of the several finite differences.

Although there can be no difficulty in applying the formulas, it may not be improper, for the sake of illustration, to take an example. We shall choose the instance of

Venus and the Earth.

In this case a' will represent the mean distance of the Earth, and a that of Venus: wherefore,

$$\frac{a}{a'} = \alpha = 0.7323332 = \tan \frac{1}{2} \theta, \quad \theta = 71^\circ 45' 32'',$$

$$h = \frac{1}{\cos \theta} = 3.1947202, \quad \log. \sin \theta = 9.9776083.$$

The method likewise requires that there be previously calculated a sufficient number of the first coefficients in the expansion,

$$\frac{1}{\sqrt{1 + \alpha^2 - 2\alpha \cos \psi}} = \frac{1}{2} C^{(0)} + C^{(1)} \cos \psi + C^{(2)} \cos 2\psi + \dots + C^{(k)} \cos k\psi + \dots,$$

which is accomplished by rules amply detailed in all the treatises on Physical Astronomy. We next deduce the value of $a^{(k)}$, viz.

$$a^{(k)} = (2k + 1) \cdot (C^{(k)} - \sin \theta C^{(k+1)}):$$

and, with the numbers thus found, we have generally for any proposed value of k ,

$$\begin{aligned}
 b_0^{(k)} &= C^{(k)}, \\
 b_1^{(k)} &= \frac{1}{2} C^{(k)} + 1.59736 \cdot a^{(k)} \\
 b_2^{(k)} &= \left(\frac{1}{4} + \frac{k^2}{2} \right) \cdot C^{(k)} + 4.148919 \cdot a^{(k)} \\
 b_3^{(k)} &= \{ -0.008113 + 1.282453 \cdot k^2 \} \cdot C^{(k)} \\
 &\quad + \{ 10.459698 + 0.266227 k^2 \} \cdot a^{(k)} \\
 b_4^{(k)} &= \left\{ -0.512255 + 3.132352 k^2 + \frac{k^4}{24} \right\} \cdot C^{(k)} \\
 &\quad + \{ 28.09035 + 0.957713 k^2 \} \cdot a^{(k)} \\
 b_5^{(k)} &= \{ -1.861383 + 8.390554 k^2 + 0.157412 k^4 \} \cdot C^{(k)} \\
 &\quad + \{ 80.06813 + 2.719660 k^2 + 0.133113 k^4 \} \cdot a^{(k)}
 \end{aligned}$$

Nothing can be more easy than the computation of these six quantities for any assigned value of k . The other quantities, being the several orders of the finite differences of the first six, will be known when these have been computed: but it will be convenient and will often save much calculation to have an independent formula for every coefficient separately.

$$\begin{aligned}
 -\Delta b_0^{(k)} &= \frac{1}{2} C^{(k)} - 1.59736 \cdot a^{(k)} \\
 -\Delta b_1^{(k)} &= \left(\frac{1}{4} - \frac{k^2}{2} \right) C^{(k)} - 2.551559 \cdot a^{(k)} \\
 -\Delta b_2^{(k)} &= \{ 0.258113 - 0.782453 k^2 \} \cdot C^{(k)} \\
 &\quad - \{ 6.31078 + 0.266227 k^2 \} \cdot a^{(k)} \\
 -\Delta b_3^{(k)} &= \left\{ 0.504142 - 1.849899 k^2 - \frac{k^4}{24} \right\} C^{(k)} \\
 &\quad - \{ 17.63065 + 0.691486 k^2 \} \cdot a^{(k)}
 \end{aligned}$$

$$\begin{aligned}
-\Delta b_4^{(k)} &= \{1.34913 - 5.258202 k^2 - 0.115745 k^4\} C^{(k)} \\
&\quad - \{51.97778 + 1.761947 k^2 + 0.133113 k^4\} a^{(k)} \\
\Delta^2 b_0^{(k)} &= \left(\frac{1}{4} + \frac{k^2}{2}\right) C^{(k)} + 0.954199 a^{(k)} \\
\Delta^2 b_1^{(k)} &= \{-0.008113 + 0.282453 k^2\} C^{(k)} \\
&\quad + \{3.75922 + 0.266227 k^2\} a^{(k)} \\
\Delta^2 b_2^{(k)} &= \{-0.24603 + 1.067446 k^2 + 0.041667 k^4\} C^{(k)} \\
&\quad + \{11.31987 + 0.425259 k^2\} a^{(k)} \\
\Delta^2 b_3^{(k)} &= \{-0.84499 + 3.408303 k^2 + 0.074078 k^4\} C^{(k)} \\
&\quad + \{34.34714 + 1.070461 k^2 + 0.133113 k^4\} a^{(k)} \\
-\Delta^3 b_0^{(k)} &= \{0.25811 + 0.217547 k^2\} C^{(k)} \\
&\quad - \{2.80502 + 0.266227 k^2\} a^{(k)} \\
-\Delta^3 b_1^{(k)} &= \{0.23792 - 0.784993 k^2 - 0.041667 k^4\} C^{(k)} \\
&\quad - \{7.56065 + 0.159032 k^2\} a^{(k)} \\
-\Delta^3 b_2^{(k)} &= \{0.59896 - 2.340857 k^2 - 0.032411 k^4\} C^{(k)} \\
&\quad - \{23.02727 + 0.645158 k^2 + 0.13113 k^4\} a^{(k)} \\
\Delta^4 b_0^{(k)} &= \{0.020197 + 1.002540 k^2 + 0.041667 k^4\} C^{(k)} \\
&\quad + \{4.75563 - 0.107195 k^2\} a^{(k)} \\
\Delta^4 b_1^{(k)} &= \{-0.36104 + 1.555864 k^2 - 0.009256 k^4\} C^{(k)} \\
&\quad + \{15.46662 + 0.486126 k^2 + 0.133113 k^4\} a^{(k)} \\
-\Delta^5 b_0^{(k)} &= \{0.38124 - 0.553324 k^2 + 0.050923 k^4\} C^{(k)} \\
&\quad - \{10.71099 + 0.593321 k^2 + 0.133113 k^4\} a^{(k)}.
\end{aligned}$$

According to these formulas the calculation of any of the coefficients is an easy arithmetical process. In order to be able to compute, in any term of the

expansion of $\frac{1}{D}$, the part of any proposed order with respect to e and e' , nothing more is wanting than a method for reducing

$$\beta s'^2 s^i \cos(\phi - \phi' + \sigma - \sigma')$$

to a series of simple cosines. On this point some observations will be offered below: but, without proceeding further, there is no difficulty in this respect, when we confine our views to quantities not passing the second or third order, which comprehends all the perturbations useful in astronomy, except the inequalities of very long periods.

If we combine the planets two and two, as is done in the sixth chapter of the sixth book of the *Mécanique Céleste*, and for every two planets construct a formula such as is exhibited above for Venus and the Earth, limiting the extent of the calculation according to the nature of the case, the theory of the planetary disturbances would be rendered more accessible, and would be freed from the tedious and disgusting labour which has rendered astronomers averse from cultivating this branch of their science.

6. The expression,

$$s'^2 s' \cos k(\phi - \phi' + \sigma - \sigma')$$

may be reduced to this form,

$$\begin{aligned} & \cos k(\phi - \phi') \cdot \left\{ (s^i \cos k\sigma) (s'^2 \cos k\sigma') + (s^i \sin k\sigma) (s'^2 \sin k\sigma') \right\} \\ & - \sin k(\phi - \phi') \cdot \left\{ (s^i \sin k\sigma) (s'^2 \cos k\sigma') - (s^i \cos k\sigma) (s'^2 \sin k\sigma') \right\}. \end{aligned}$$

Here the quantities within the brackets are serieses, of which each contains the mean anomaly of only one planet, and comes under one or other of eleven different forms, namely, the six,

$$\cos k\sigma, s \cos k\sigma, s^2 \cos k\sigma, \dots \dots s^5 \cos k\sigma,$$

and the five,

$$\sin k\sigma, s \sin k\sigma, s^2 \sin k\sigma, \dots \dots s^4 \sin k\sigma,$$

the quantity $s^5 \sin k\sigma$, which is of the sixth order, being omitted. None of these serieses, when carried to quantities of the fifth order inclusively, and arranged according to the sines and cosines of the multiples of the mean anomaly, con-

tain more than six terms, and they thus afford a ready way of calculating the part of

$$s'^2 s^i \cos k(\varphi - \varphi' + \sigma - \sigma')$$

of any proposed order with respect to e and e' .

These series are as follow :

$$\begin{aligned} \cos k\sigma = & \left(1 - k^2 e^2 - \frac{9}{64} k^2 e^4 + \frac{k^4 e^4}{4}\right) \\ & - \left(\frac{5}{4} k^2 e^2 + \frac{1}{16} k^2 e^4 - \frac{5}{12} k^4 e^4\right) \cdot e \cos \mu \\ & + \left(k^2 - \frac{4}{3} k^2 e^2 - \frac{k^4 e^2}{3}\right) \cdot e^2 \cos 2\mu \\ & + \left(\frac{5}{4} k^2 - \frac{27}{16} k^4 e^2 - \frac{5}{8} k^4 e^2\right) \cdot e^3 \cos 3\mu \\ & + \left(\frac{k^4}{12} + \frac{283}{192} k^2\right) \cdot e^4 \cos 4\mu \\ & + \left(\frac{5k^4}{24} + \frac{7k^2}{4}\right) \cdot e^5 \cos 5\mu. \end{aligned}$$

$$\begin{aligned} \sin k\sigma = & \left(2k - \frac{k e^2}{4} + \frac{5k e^4}{96} - k^3 e^2 + \frac{13k^3 e^4}{96} + \frac{k^5 e^4}{6}\right) \cdot e \sin \mu \\ & + \left(\frac{5k}{4} - \frac{11k e^2}{24} - \frac{5k^3 e^2}{4}\right) \cdot e^2 \sin 2\mu \\ & + \left(\frac{13k}{24} - \frac{43}{64} k e^2 - \frac{k^3}{3} - \frac{307k^3 e^2}{192} - \frac{k^4 e^4}{12}\right) \cdot e^3 \sin 3\mu \\ & + \left(\frac{103}{96} k + \frac{5}{8} k^3\right) \cdot e^4 \sin 4\mu \\ & + \left(\frac{1097}{960} k + \frac{179}{192} k^3 + \frac{k^5}{60}\right) \cdot e^5 \sin 5\mu. \end{aligned}$$

$$\begin{aligned} s \cos k\sigma = & -\frac{e^2}{2} + \frac{k^2 e^4}{8} \\ & + \left(1 - \frac{3e^2}{8} + \frac{5e^4}{192} - \frac{k^2 e^2}{2} + \frac{37k^2 e^4}{96} + \frac{k^4 e^4}{12}\right) \cdot e \cos \mu \\ & + \left(\frac{1}{2} - \frac{e^2}{3} - k^2 e^2\right) \cdot e^2 \cos 2\mu \end{aligned}$$

$$\begin{aligned}
& + \left(\frac{3}{8} - \frac{45e^2}{128} + \frac{k^2}{2} - \frac{183 \cdot k^2 e^2}{128} - \frac{k^4 e^2}{8} \right) \cdot e^3 \cos 3\mu \\
& + \left(\frac{1}{3} + \frac{7k^2}{8} \right) \cdot e^4 \cos 4\mu \\
& + \left(\frac{125}{384} + \frac{475}{384} k^2 + \frac{k^4}{24} \right) \cdot e^5 \cos 5\mu \\
s \sin k\sigma = & -k \left(\frac{7}{8} e^2 - \frac{3}{32} e^4 - \frac{5k^2 e^2}{24} \right) \cdot e \sin \mu \\
& + k \left(1 - \frac{23}{24} e^2 - \frac{k^2 e^2}{3} \right) \cdot e^2 \sin 2\mu \\
& + k \left(\frac{9}{8} - \frac{115 \cdot e^2}{96} - \frac{35k^2 e^2}{48} \right) \cdot e^3 \sin 3\mu \\
& + \left(\frac{59}{48} k + \frac{k^3}{6} \right) \cdot e^4 \sin 4\mu \\
& + \left(\frac{11}{8} k + \frac{19}{48} k^3 \right) \cdot e^5 \sin 5\mu \\
s^2 \cos k\sigma = & \frac{e^2}{2} - \frac{k^2 e^4}{4} \\
& - \left(\frac{e^2}{2} - \frac{e^4}{24} + \frac{k^2 e^4}{8} \right) \cdot e \cos \mu \\
& + \left(\frac{1}{2} - \frac{e^2}{2} \right) \cdot e^2 \cos 2\mu \\
& + \left(\frac{1}{2} - \frac{9e^2}{16} - \frac{7k^2 e^2}{16} \right) \cdot e^3 \cos 3\mu \\
& + \left(\frac{1}{2} + \frac{k^2}{4} \right) \cdot e^4 \cos 4\mu \\
& + \left(\frac{25}{48} + \frac{9k^2}{16} \right) \cdot e^5 \cos 5\mu \\
s^2 \sin k\sigma = & \left(\frac{k e^2}{2} + \frac{k e^4}{12} - \frac{k^3 e^4}{12} \right) \cdot e \sin \mu \\
& - \frac{3k e^2}{8} \cdot e^2 \sin 2\mu \\
& + \left(\frac{k}{2} - \frac{5k e^2}{6} - \frac{k^3 e^2}{12} \right) \cdot e^3 \sin 3\mu
\end{aligned}$$

$$\begin{aligned}
& + \frac{13k}{16} \cdot e^4 \sin 4\mu \\
& + \left(\frac{13k}{12} + \frac{k^3}{12} \right) \cdot e^5 \sin 5\mu \\
s^3 \cos k\sigma = & - \frac{3}{8} e^4 \\
& + \left(\frac{3}{4} e^2 - \frac{3e^4}{16} + k^2 e^4 \right) \cdot e \cos \mu \\
& + \left(\frac{1}{4} - \frac{9e^2}{32} + \frac{k^3 e^3}{8} \right) \cdot e^3 \cos 3\mu \\
& + \frac{3}{8} \cdot e^4 \cos 4\mu \\
& + \left(\frac{15}{32} + \frac{k^3}{8} \right) \cdot e^5 \cos 5\mu \\
s^3 \sin k\sigma = & - \frac{7k e^4}{16} \cdot e \sin \mu + \frac{k e^2}{2} \cdot e^2 \sin 2\mu + \frac{3k e^2}{32} \cdot e^3 \sin 3\mu \\
& + \frac{k}{2} \cdot e^4 \sin 4\mu + \frac{17k}{32} \cdot e^5 \sin 5\mu \\
s^4 \cos k\sigma = & \frac{3}{8} e^4 - \frac{e^4}{2} \cdot e \cos \mu + \frac{e^2}{2} \cdot e^2 \cos 2\mu + \frac{e^2}{4} \cdot e^3 \cos 3\mu \\
& + \frac{1}{8} \cdot e^4 \cos 4\mu + \frac{1}{4} \cdot e^5 \cos 5\mu \\
s^4 \sin k\sigma = & \frac{k e^4}{4} \cdot e \sin \mu + \frac{3k e^2}{8} \cdot e^3 \sin 3\mu + \frac{1}{8} \cdot e^5 \sin 5\mu \\
s^5 \cos k\sigma = & \frac{5e^4}{8} \cdot e \cos \mu + \frac{5e^2}{16} \cdot e^3 \cos 3\mu + \frac{1}{16} e^5 \cos 5\mu
\end{aligned}$$

The use of these serieses is obvious. If we wish to determine all the arguments of the order $e^x e^{x'}$ in the term multiplied by $\cos k(\varphi - \varphi' + \sigma - \sigma')$, of the development of $\frac{1}{D}$, x and x' representing two positive integer numbers, zero included, of which the sum does not exceed 5; we first set aside all the parts of

the expression in which i is greater than x , or i' greater than x' , for these contain no quantities of the order $e^x e^{x'}$. Let

$$\Delta^i b_{\nu}^{(k)} \times \beta s^i s'^{k-i} \cos k(\phi - \phi' + \sigma - \sigma')$$

be one of the remaining parts, in which i is not greater than x , nor i' greater than x' ; in the serieses $s^i \cos k\sigma$ and $s^i \sin k\sigma$, take the terms $A e^x \cos x\mu$ and $B e^x \sin x\mu$; and, in $s'^{k-i} \cos k\sigma'$ and $s'^{k-i} \sin k\sigma'$, take the terms $A' e^{x'} \cos x'\mu'$ and $B' e^{x'} \sin x'\mu'$; then all the arguments of the order $e^x e^{x'}$ will be contained in the formula

$$\begin{aligned} & \Delta^i b_{\nu}^{(k)} \times \beta e^x e^{x'} \times \\ & \cos k(\phi - \phi') \cdot \{A A' \cos x\mu \cos x'\mu' + B B' \sin x\mu \sin x'\mu'\} \\ & - \sin k(\phi - \phi') \cdot \{A' B \sin x\mu \cos x'\mu' - A B' \cos x\mu \sin x'\mu'\}. \end{aligned}$$

And thus are computed all the quantities of the order $e^x e^{x'}$ in any term of the development of $\frac{1}{D}$. The procedure is exactly the same with that followed in the expansion of the first part of the disturbing function in § 2. All the arguments of the order $e^x e^{x'}$ are only four, comprehended in the formula

$$k(\phi - \phi') \pm x\mu \pm x'\mu',$$

which represents all the different ways of combining $x\mu$ and $x'\mu'$, by addition and subtraction, with $k(\phi - \phi')$. Hence it is easy to ascertain the orders of the same argument, or the relative magnitude of its coefficients, as it recurs in different terms of the development of $\frac{1}{D}$.

7. We have next to consider the parts of the disturbing function which depend on the inclination of the orbits.

$$\text{Development of } \sin^2 \frac{1}{2} I \cdot \frac{r r'}{D^3} \cdot q.$$

Omitting quantities above the third order with respect to s and s' in the expression of $\frac{1}{D}$ found in § 3, we have

$$\begin{aligned} \frac{1}{D} &= B^{(0)} + B^{(1)} s' + B^{(2)} s'^2 + B^{(3)} s'^3 \\ &\quad - \Delta B^{(0)} s - \Delta B^{(1)} 2 s s' - \Delta B^{(2)} 3 s s'^2 \\ &\quad + \Delta^2 B^{(0)} s^2 + \Delta^2 B^{(1)} 3 s^2 s' \\ &\quad - \Delta^3 B^{(0)} s^3. \end{aligned}$$

As the values of $B^{(0)}$, $B^{(1)}$, &c., contain $\frac{1}{D_0}$ and its powers, they may be regarded as functions of $\cos \psi$: taking the differentials with regard to this variable, we get,

$$\begin{aligned} \frac{dB^{(0)}}{d(\cos \psi)} &= \frac{aa'}{D_0^3} = \frac{aa'}{f} \times \frac{f}{D_0^3} = \frac{aa'}{f} \times B'^{(0)}, \\ \frac{dB^{(1)}}{d(\cos \psi)} &= \frac{aa'}{f} \left(\frac{1}{2} \cdot \frac{f}{D_0^3} + \frac{3}{2} \cdot \frac{f^2}{D_0^5} \right) = \frac{aa'}{f} \times B'^{(1)}, \\ \frac{dB^{(2)}}{d(\cos \psi)} &= \frac{aa'}{f} \left(\frac{3}{8} \frac{f}{D_0^3} + \frac{6-3h}{4} \cdot \frac{f^2}{D_0^5} + \frac{15}{8} \cdot \frac{f^3}{D_0^7} \right) = \frac{aa'}{f} \times B'^{(2)}, \\ \frac{dB^{(3)}}{d(\cos \psi)} &= \frac{aa'}{f} \times \left(\frac{5}{16} \cdot \frac{f}{D_0^3} + \frac{27-18h}{16} \cdot \frac{f^2}{D_0^5} + \frac{45-30h}{16} \cdot \frac{f^3}{D_0^7} + \frac{35}{16} \cdot \frac{f^4}{D_0^9} \right) \\ &= \frac{aa'}{f} \times B'^{(3)}. \end{aligned}$$

If we now differentiate the above formula for $\frac{1}{D}$, and observe that

$$\frac{aa'}{f} = \frac{aa'}{a'^2 - a^2} = \frac{1}{2} \sqrt{h^2 - 1} = \frac{\tan \theta}{2},$$

the result, when the new symbols are introduced, will be as follows :

$$\begin{aligned} \frac{rr'}{D^3} &= \frac{\tan. \theta}{2} \times \left\{ B'^{(0)} + B'^{(1)} s^1 + B'^{(2)} s'^2 + B'^{(3)} s'^3 \right. \\ &\quad - \Delta B'^{(0)} s - \Delta B'^{(1)} 2 s s^1 - \Delta B'^{(2)} 3 s s'^2 \\ &\quad + \Delta^2 B'^{(0)} s^2 + \Delta^2 B'^{(1)} 3 s^2 s^1 \\ &\quad \left. - \Delta^3 B'^{(0)} s^3. \right\} \end{aligned}$$

The values of $B^{(0)}$, $B^{(1)}$, &c., may be reduced to expressions that contain only $\frac{1}{D_0}$ and $\frac{f}{D_0^3}$ and their second and fourth differentials, by the same process that was applied to $B^{(0)}$, $B^{(1)}$, &c., in § 4: and in this manner we obtain,

$$\begin{aligned}
 B^{(0)} &= \frac{f}{D_0^3} \\
 B^{(1)} &= -\frac{1}{2} \cdot \frac{1}{D_0} - 2 \frac{d d \frac{1}{D_0}}{d \psi^2} + \frac{4h+1}{2} \cdot \frac{f}{D_0^3}, \\
 B^{(2)} &= -\frac{3h+2}{4} \cdot \frac{1}{D_0} - (3h+2) \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} \\
 &\quad + \left(3h^2 + 2h - \frac{3}{4}\right) \cdot \frac{f}{D_0^3} - \frac{1}{2} \cdot \frac{d d \frac{f}{D_0^3}}{d \psi^2} \\
 B^{(3)} &= -\frac{24h^2 + 27h + 1}{24} \cdot \frac{1}{D_0} - \frac{48h^2 + 54h + 1}{12} \cdot \frac{d d \frac{1}{D_0}}{d \psi^2} + \frac{1}{3} \cdot \frac{d^4 \frac{1}{D_0}}{d \psi^4} \\
 &\quad + \frac{96h^3 + 108h^2 - 23h - 33}{24} \cdot \frac{f}{D_0^3} - \frac{10h + 9}{12} \cdot \frac{d d \frac{f}{D_0^3}}{d \psi^2}.
 \end{aligned}$$

The term multiplied by $\cos k\psi$ in the expansion of $\frac{rr'}{D^3}$, will now be obtained by substituting in $B^{(0)}$, $B^{(1)}$, &c., the parts of $\frac{1}{D_0}$, $\frac{f}{D_0^3}$, and their differentials, multiplied by the same cosine. Let

$$\frac{\cos k\psi}{a'} \times b_0^{(k)}, \frac{\cos k\psi}{a'} \times b_1^{(k)}, \frac{\cos k\psi}{a'} \times b_2^{(k)}, \frac{\cos k\psi}{a'} \times b_3^{(k)},$$

denote the expressions into which

$$B^{(0)}, B^{(1)}, B^{(2)}, B^{(3)},$$

are changed by the substitutions mentioned; the quantity sought, or the part of the expansion of $\sin^2 \frac{1}{2} I \times \frac{rr'}{D^3} \times q$ multiplied by $\cos k\psi$, will be thus expressed,

$$\frac{\sin^2 \frac{1}{2} I \cdot \cos k (\varphi - \varphi' + \sigma - \sigma') \times q}{a^j} \times$$

$$\frac{\tan \theta}{2} \cdot \left\{ b_0^{(k)} + b_1^{(k)} s' + b_2^{(k)} s'^2 + b_3^{(k)} s'^3 \right.$$

$$- \Delta b_0^{(k)} s - \Delta b_1^{(k)} 2 s s' - \Delta b_2^{(k)} 3 s s'^2$$

$$+ \Delta b_0^{(k)} s^2 + \Delta^2 b_1^{(k)} 3 s^2 s' - \Delta^3 b_0^{(k)} s^3 :$$

and the values of $b_0^{(k)}$, $b_1^{(k)}$, &c., will be as follow:

$$b_0^{(k)} = h \cdot a^{(k)},$$

$$b_1^{(k)} = \left(-\frac{1}{2} + 2k^2\right) C^{(k)} + \frac{4k^3 + h}{2} \cdot a^{(k)}$$

$$b_2^{(k)} = (3h^2) \cdot \frac{4k^2 - 1}{4} \cdot C^{(k)} + \left(3k^3 + 2h^2 \frac{3}{2} h + \frac{h}{2} \cdot k^2\right) \cdot a^{(k)}$$

$$b_3^{(k)} = \left\{ -\frac{24h^3 + 27h + 1}{24} + \frac{48h^2 + 54h + 1}{12} \cdot k^2 + \frac{k^4}{3} \right\} \cdot C^{(k)}$$

$$+ \left\{ \frac{96h^4 + 108h^3 - 23h^2 - 33h}{24} + \frac{10h^2 + 9h}{12} k^2 \right\} \cdot a^{(k)}.$$

By taking the several orders of the finite differences of these four quantities, the other six coefficients may be numerically computed, or an independent formula may be found for calculating each of the six separately. The expansion of this part of the disturbing function is therefore reduced to the expressing of

$$\beta s'^i s^i \cos k (\varphi - \varphi' + \sigma - \sigma') \times q$$

in a series of simple cosines, i' and i being any positive numbers, zero included, the sum of which, $i' + i$, does not exceed 3, and β being the coefficient of $s'^i s^i$ in $(s' + s)^{i' + i}$. By substituting what q stands for, we have,

$$s'^i s^i \cos k (\varphi - \varphi' + \sigma - \sigma') \times q$$

$$= \frac{1}{2} s'^i s^i \cos (k - 1) (\varphi - \varphi' + \sigma - \sigma')$$

$$+ \frac{1}{2} s'^i s^i \cos (k + 1) (\varphi - \varphi' + \sigma - \sigma')$$

MDCCCXXXIII.

4 G

$$\begin{aligned}
& -\frac{1}{2} s'' s^i \cos(\overline{k-1} . -\phi \overline{k+1} . \phi' - 2\nu + \overline{k-1} . \sigma - \overline{k+1} . \sigma') \\
& -\frac{1}{2} s'' s^i \cos(\overline{k+1} . \phi - \overline{k-1} . \phi' - 2\nu + \overline{k+1} . \sigma - \overline{k-1} . \sigma').
\end{aligned}$$

As the arguments in the expansions of these four terms are different, each term must be computed separately, for which purpose the method in § 6 may be used. Thus

$$\begin{aligned}
& s'' s^i \cos(\overline{k-1} . \phi - \overline{k+1} . \phi' - 2\nu + \overline{k-1} . \sigma - \overline{k+1} . \sigma') \\
& = \cos(\overline{k-1} . \phi - \overline{k+1} . \phi' - 2\nu) . \left\{ \left(s^i \cos(k-1) . \sigma \right) \left(s'' \cos(k+1) \sigma' \right) \right. \\
& \quad \left. + \left(s^i \sin(k-1) \sigma \right) . \left(s'' \sin(k+1) \sigma' \right) \right\} \\
& - \sin(\overline{k-1} . \phi - \overline{k+1} . \phi' - 2\nu) . \left\{ \left(s^i \sin(k-1) \sigma \right) . \left(s'' \cos(k+1) \sigma' \right) \right. \\
& \quad \left. - \left(s^i \cos(k-1) \sigma \right) . \left(s'' \sin(k+1) \sigma' \right) \right\};
\end{aligned}$$

and the quantities within the brackets being known serieses, the part of the expansion of any order $e^{\nu} e^{\nu'}$, is readily obtained.

8. One part of the disturbing function yet remains to be considered.

$$\text{Expansion of } \sin^4 \frac{1}{2} I \times \frac{1}{2} . \frac{r^2 r'^2}{D^5} \times q^2.$$

In the expression of $\frac{r r'}{D^3}$ found in § 7, leave out quantities of the second and third order with respect to s and s' , and we shall have,

$$\begin{aligned}
\frac{1}{2} . \frac{r r'}{D^3} &= \frac{\tan \theta}{2} \times \left\{ \frac{1}{2} B^{(0)} + \frac{1}{2} B^{(1)} . e' \cos \mu' \right. \\
&\quad \left. - \frac{1}{2} \Delta B^{(0)} . e \cos \mu. \right.
\end{aligned}$$

Now let

$$\begin{aligned}
\frac{1}{2} . \frac{d B^{(0)}}{d(\cos \psi)} &= \frac{a a'}{f} . \frac{f^2}{D_0^5} = \frac{a a'}{f} \times B''^{(0)} \\
\frac{1}{2} . \frac{d B^{(1)}}{d(\cos \psi)} &= \frac{a a'}{f} \left(\frac{3}{4} . \frac{f^2}{D_0^5} + \frac{15}{4} . \frac{f^3}{D_0^7} \right) = \frac{a a'}{f} \times B''^{(1)};
\end{aligned}$$

and differentiate the formula for $\frac{1}{2} . \frac{r r'}{D^3}$ relatively to the variable $\cos \psi$, intro-

ducing the new symbols, and observing that $\frac{a a'}{f} = \frac{\tan \theta}{2}$, the result will be,

$$\frac{1}{2} \cdot \frac{r^2 r'^2}{D^5} = \frac{\tan^2 \theta}{4} \times \left\{ B''^{(0)} + B''^{(1)} e' \cos \mu' \right. \\ \left. - \Delta B''^{(0)} e \cos \mu. \right.$$

The quantities $B''^{(0)}$ and $B''^{(1)}$, when expressed as before in terms of $\frac{1}{D_0}$ and $\frac{f}{D_0^3}$ and their differentials, will be as follow:

$$B''^{(0)} = \frac{1}{2} \cdot \frac{f^2}{D_0^5} = -\frac{1}{2} \cdot \frac{1}{D_0} - 2 \frac{d d \frac{1}{D_0}}{d \psi^2} + 2 h \cdot \frac{f}{D_0^3}, \\ B''^{(1)} = \frac{1}{4} \cdot \frac{f^2}{D_0^5} + \frac{15}{4} \cdot \frac{f^2}{D_0^7} = \\ - (8 h + 1) \cdot \left(\frac{1}{4} \cdot \frac{1}{D_0} + \frac{d d \frac{1}{D_0}}{d \psi^2} \right) - (8 h^2 + h - \frac{9}{2}) \cdot \frac{f}{D_0^3} - \frac{d d \frac{f}{D_0^3}}{d \psi^2}.$$

Proceeding as before, let

$$\frac{\cos k \psi}{a'} \times b''^{(k)}_0, \text{ and } \frac{\cos k \psi}{a'} \times b''^{(k)}_1,$$

represent the expressions into which

$$B''^{(0)} \text{ and } B''^{(1)}$$

are changed, when we substitute, instead of $\frac{1}{D_0}$ and $\frac{f}{D_0^3}$ and their differentials, the parts of these quantities multiplied by $\cos k \psi$: then the part multiplied by $\cos k \psi$ in the expansion of $\sin^4 \frac{1}{2} I \times \frac{1}{2} \times \frac{r^2 r'}{D^5} \times q^2$, will be thus expressed:

$$\frac{\sin^4 \frac{1}{2} I \times \cos k (\phi - \phi' + \sigma - \sigma') \times q^2}{a'} \times \\ \frac{\tan^2 \theta}{4} \times \left\{ b''^{(k)}_0 + b''^{(k)}_1 \cdot e \cos \mu' \right. \\ \left. - \Delta b''^{(k)}_0 e \cos \mu; \right.$$

and the values of $b''^{(k)}_0$ and $b''^{(k)}_1$ will be as follow:

$$b''^{(k)}_0 = \frac{4 k^2 - 1}{2} C^{(k)} + 2 h^2 \cdot a^{(k)}, \\ b''^{(k)}_1 = (8 h + 1) \frac{4 k^2 - 1}{4} \cdot C^{(k)} + \left\{ 8 h^3 + h^2 - \frac{9}{4} h + h k^2 \right\} \cdot a^{(k)}.$$

4 G 2

The coefficients for any proposed value of k may now be readily computed; and nothing is wanting in this part of the problem but to reduce the factor,

$$\cos k(\varphi - \varphi' + \sigma - \sigma'). \left\{ \cos(\varphi - \varphi' + \sigma - \sigma') - \cos(\varphi + \varphi' + \sigma + \sigma' - 2\tau) \right\}^2,$$

to the form,

$$M + M' \times e \sin \mu + M'' \times e' \sin \mu',$$

and then to multiply by it, retaining in the product only quantities of the first order relative to e and e' . Now in this there is no difficulty: but the complete development of the expression would be bulky, and would contain many arguments, the greater part of which are insignificant and useless, although some of them deserve attention in particular researches. Leaving astronomers to select from the general expression the arguments which may suit their purpose, we shall here close what we had to offer respecting the development of the disturbing function, without adding to the length of this paper by any application of what we have written.

May 30, 1833.

XXV. *On the Figures obtained by strewing Sand on Vibrating Surfaces, commonly called Acoustic Figures.* By CHARLES WHEATSTONE, Esq. Communicated by MICHAEL FARADAY, Esq., D.C.L. F.R.S., &c. &c. &c.

Received February 12,—Read March 14, 1833.

§ 1.

HALF a century has nearly elapsed since the attention of philosophers was first called to the curious phenomena exhibited when sand is strewed on vibrating surfaces. Long before this time, GALILEO had noticed that small pieces of bristle laid on the sounding-board of a musical instrument, were violently agitated on some parts of the surface, whilst on other parts they did not appear to move; and our own countryman Dr. HOOKE, whose sagacity in anticipating many of the discoveries of later times has been so frequently remarked, had proposed to observe the vibrations of a bell by strewing flour upon it. But to CHLADNI is due the sole merit of having discovered the symmetrical figures exhibited on plates of regular forms when caused to sound. His first investigations on this subject, *Entdeckungen über die Theorie des Klanges*, were published in 1787; this work was followed by his *Akustik* in 1802, and his *Neue Beyträge zur Akustik*, 1817. A French translation, by himself, of his second work was published at Paris in 1809.

All the figures obtained by CHLADNI on square surfaces are delineated in pages 611, 613, 615; they are copied from the *Neue Beyträge*, which work contains his most mature experiments; but not having been translated either into French or English, it is but little known in this country. The following are the general results deduced by CHLADNI from his observations respecting these figures: his works may be referred to for the details omitted, and for those concerning the vibrations of plates in general.

In all the modes of vibration of a square or rectangular plate, the figures,

even if they consist of diagonal or tortuous lines, may all be referred to a certain number of nodal lines in the two directions parallel to the sides.

To establish a convenient notation for these figures, he represents the lines in the two directions by numbers separated by a vertical line. Thus, for example, $3|0$ signifies the mode of vibration, in which there are three lines in one direction and none in the other; $5|2$ denotes that in which there are five lines parallel to one side, and two to the other, &c.

The nodal lines, which may always be considered as having been originally straight, may curve themselves more or less; and in general the flexions of these lines, whether they adjoin each other or are separated by a straight line, mutually approach to or recede from each other. In some modes of vibration the nodal lines are never straight.

In some instances, the same mode of vibration may manifest itself in two essentially different ways, according as the flexions of the lines, or the greater number of them, are inward or outward; in the first case, the sound is usually graver than in the second. This difference is remarked in those figures where there is an entire number of flexions, as in $2|0$, $3|1$, $4|0$, $5|3$, $6|2$, &c.; but never in those figures where there are $1\frac{1}{2}$, $2\frac{1}{2}$, &c., as in $3|0$, $4|1$, $5|0$, $5|2$, &c. To distinguish the first from the second figure, CHLADNI places a horizontal line above the numbers in the first case, and below them in the second case, thus, $\overline{4|2}$, $\underline{4|2}$.

When two or more figures having the same notation, occur in the Table, the others are to be considered as distortions of the first, occasioned by altering the fixed points, and the place at which the bow is applied.

If four plates of the same size, and upon which the same figure has been produced, be placed together so as to form a larger square, this compound figure may also be more or less accurately produced on a single larger plate. Several instances of this may be seen by reference to the Table of figures.

The following Table contains the relative sounds (expressed both by their musical names and the number of their vibrations,) of all the modes of vibration of a square plate, experimentally ascertained by CHLADNI. The horizontal series of numbers denotes the lines parallel to one of the sides, and the vertical series those parallel to the other.

TABLE.

1		G, 6								
2	D—, 9— E..F, 10+	B, 15	A'..B' 27+, 28—							
3	G $\sharp$, 25	B', 30 C $\sharp$ +, 32? 33?	F $\sharp$ $\sharp$, 45	C $\sharp$ + 64, 65						
4	G $\sharp$ $\sharp$ —, 49— G $\sharp$ $\sharp$ $\sharp$, 50	B $\sharp$ —, 55, 56—	C $\sharp$ $\sharp$ $\sharp$, 70 D $\sharp$, 72	F $\sharp$ $\sharp$ $\sharp$, 90, 91	B $\sharp$ —, 110+, 112					
5	E $\sharp$ +, 81	F $\sharp$, 84 F $\sharp$ $\sharp$ $\sharp$, 90 91	G $\sharp$ $\sharp$ $\sharp$, 98, 99, 100—	B', 119 120 C $\sharp$, 125 126 128—	D $\sharp$ $\sharp$ $\sharp$, 150, 153	F $\sharp$ $\sharp$ $\sharp$, 180				
6	B $\sharp$, 120 121 C $\sharp$ —, 125 126	C $\sharp$, 128	C $\sharp$ $\sharp$ $\sharp$, 135 140 D $\sharp$, 144	E $\sharp$, 160 162	G $\sharp$, 189 192 G $\sharp$ $\sharp$ $\sharp$, 196 198 200—	B $\flat$ $\sharp$, 224+ 231—	C $\sharp$, 256 264			
7	F $\sharp$, 169	F $\sharp$ F $\sharp$ $\sharp$ $\sharp$ 175? 180?	F $\sharp$ $\sharp$ $\sharp$ + 180+? 189—?	G $\sharp$ $\sharp$ $\sharp$ +, 209 210 A $\sharp$, 216 220	B $\sharp$, 240 240	C $\sharp$ $\sharp$ $\sharp$, 275 280 D $\sharp$ $\sharp$ $\sharp$, 286 288	E $\sharp$, 320 324 325	F $\sharp$ $\sharp$ $\sharp$, 360 364		
8	B $\flat$ $\sharp$, 224 225 B $\flat$ $\sharp$ + 225? 231?		B $\sharp$, 240 242 C $\sharp$ —245 250	C $\sharp$ +, 256+ 264—	D $\sharp$, 286 288 D $\sharp$ $\sharp$ $\sharp$, 294 299	F $\sharp$, 336 338	G $\sharp$, 377+ 384 G $\sharp$ $\sharp$ $\sharp$, 390 392	A $\sharp$, 432 435	B $\sharp$, 480	
9	D $\sharp$, 289		E $\sharp$ — 315	F $\sharp$ 330 336 F $\sharp$ +, 343 345	F $\sharp$ $\sharp$ $\sharp$, 360	G $\sharp$ $\sharp$ $\sharp$ —390 392	B $\flat$ $\sharp$, 450	C $\sharp$ —, 495 C $\sharp$ 510 512	C $\sharp$ $\sharp$ $\sharp$ + 561	D $\sharp$ $\sharp$ $\sharp$, 612
	0	1	2	3	4	5	6	7	8	9

The figures placed as exponents indicate the octaves in which the sounds occur; and the characters + and — denote that the sounds to the characters of which they are affixed are respectively sharper and flatter than the true intervals.

Having thus briefly stated the general results deduced by CHLADNI from his experimental researches, I shall proceed to class and analyse the phenomena ; and I shall endeavour to show, that all the figures of vibrating surfaces are the resultants of very simple modes of vibration, oscillating isochronously, and superposed upon each other ; the resultant figure varying with the component modes of vibration, the number of the superpositions, and the angles at which they are superposed. In this first part of the investigation I shall confine myself to the figures of square and other rectangular plates.

§ 2.

The most simple modes of vibration of a rectangular surface are those which exhibit quiescent lines parallel to one of its edges. EULER has theoretically established, that a rod or band, having both its ends unfixed, can vibrate with 2, 3, 4, 5, 6, &c. quiescent lines parallel to the ends, and that the corresponding numbers of vibration are very nearly as the squares of the arithmetical progression 3, 5, 9, 11, &c. These conclusions are fully confirmed by experiment. He has proved, moreover, that when the same mode of vibration of different plates is compared, the number of vibrations is inversely as the square of the length of the plate, but that increase of breadth occasions no difference in the sound ; and that the distance from a free end to a quiescent line is rather less than half the distance between two quiescent lines.

Fig. 1. *a.* page 617, shows the number and situations of the quiescent lines in the first four modes of vibration of this series. Fig. 1. *b.* and *c.* are profiles of the preceding, and represent the curvature of each parallel fibre perpendicular to the quiescent lines at the two opposite limits of their vibration. The quantity of motion at each point is indicated by the corresponding ordinate of the curve, and its direction by its situation above or below the horizontal line. It will be convenient to distinguish these states of motion, in which every corresponding point is moving in direct opposition ; and I shall therefore call the first, *b.* positive states of vibration, and the second, *c.* negative states of vibration. When there is an even number of quiescent points, the positive state of vibration may be considered as that in which the motion at the *central* part is above the plane of equilibrium, and the negative, that in which it is below it. If we suppose two similar surfaces with the same number of quiescent lines to

be superposed, and both to vibrate in concurrence, i. e. both either positively or negatively, they will mutually assist each other's effects; but if they vibrate in opposing directions, they will destroy each other's motions, and the entire surface will be at rest.

§ 3.

When the rectangular surface is equilateral, it is obvious that it may vibrate in two different rectangular directions, so as to give the same sound, and present the same arrangement of quiescent lines. Now this plate may be excited at various points where the motion of each mode of vibration is at its maximum, in the same direction, and of equal intensity: such being the case, there is no reason why one mode of vibration should be produced in preference to the other; and on calculating the effect of such coexistence, it will be found that the resultants of these combined modes of vibration, similar in everything but in their direction with regard to the sides of the plate, give rise to new quiescent lines which accurately correspond with figures described by CHLADNI; while the number of vibrations does not materially differ from that of the component modes of vibration.

The principal results of the superposition of two similar modes of vibration are these: 1st, The points where the quiescent lines of each figure intersect each other, remain quiescent points in the resultant figure; 2ndly, The quiescent lines of one figure are obliterated when superposed by the vibrating parts of the other; 3rdly, New quiescent points, which may be called points of compensation, are formed wherever the vibrations in opposite directions neutralize each other; and, lastly, At all other points the motion is as the sum of the concurring, or the difference of the opposing vibrations.

A primary figure, having an even number of quiescent lines, may be superposed two ways, and may consequently give rise to two distinct resultant figures: one, when the central vibrating parts concur; and the other, when they are in opposition; but if the number of the quiescent lines in the primary figure be uneven, there can be only one resultant figure.

The quiescent lines which thus result may be very easily ascertained. I will take as an example the first mode of vibration, having two parallel quiescent lines; this being superposed in two rectangular directions, and so that the states of vibration are opposing (page 617, fig. 2.), it is obvious that no lines of

compensation can exist in the four rectangular segments *a a a a*, as every point included within them is actuated by concurrent motions; but in all the other rectangles they must necessarily be formed, as every point within them is affected by the two opposing motions, and if the two modes be of equal intensity, the compensations must occur at every point equally distant from the two rectangular quiescent lines, each appertaining to a different mode of vibration. The resultant figure will thus be found to consist of two diagonal lines perpendicular to each other, and passing through the centre of the plate.

But if the two superpositions vibrate in concurrence, the rectangles *b b b b* will be free from compensating points; but these will occur in the other rectangles, and form the figure represented (fig. 3.), which also consists of diagonal lines.

In the same manner the resultant of any two similar modes of vibration with nodal lines, parallel to the sides, may be proved to consist of lines parallel to the diagonals.

§ 4.

It is not a necessary condition for the vibrations of a square plate that the primary nodal lines shall be parallel to a side; they may also be parallel to a diagonal, or to any line intermediate between a transverse and a diagonal line. In these cases the superpositions take place according to the following rule: That the axes of the superposed modes of vibration must make equal angles with a transversal line passing through the centre; for otherwise the modes of vibration would not be similar. By the axis of a primary mode of vibration, I mean a straight line passing through the centre of the plate and parallel to the quiescent lines. Considerations of the kind already employed will show that in all these instances the resultant figures consist of lines parallel to the edges of the plate, and that they are always the same in number as the nodal lines of a component mode of vibration, but differently distributed in the two directions, according as the angle of superposition varies.

The various primary modes of vibration, transverse, intermediate, and diagonal, and the angles which the quiescent lines of two similar figures make with each other when they are superposed, are represented in the first column of the general Table, page 619—633; in the second column of this Table are placed the figures resulting from their opposing superpositions, and in the third column those which arise from their concurring superpositions.

We obtain by experiment a limited number only of figures which can be considered the resultants of primary modes of vibration consisting of any given number of oblique lines; but it would seem, that as the various degrees of obliquity are infinite, so there should be an infinite number of resultant figures passing into each other by insensible gradations: by calculation this should be so, but there are causes of limitation which I shall proceed to explain.

It appears that no resultant figure is maintainable unless the greatest excursions of the external vibrating parts occur at the edges of the plate. In the concurring superpositions of eight oblique lines, this condition can only be fulfilled when the angles they make with each other are either 90° , or $143^\circ 8'$; in the first case the resultant figure consists of four lines in each transverse direction, in the second of six lines in one direction and two in the other. In the opposing superpositions of the same number of lines, the condition is fulfilled when the angles at which the lines are inclined are $118^\circ 4'$ and $163^\circ 44'$; the resultant figure of the former consists of five lines in one direction and three in the other, and that of the latter of seven in one direction and one in the other.

§ 5.

I have, in the preceding sections, described the various modes of binary superpositions which may take place on a square surface. But there are numerous cases in which four superpositions may coexist, and these I shall now proceed to take into consideration.

When the axis of a primary figure corresponds either with a diagonal or with a transverse line, passing through the centre of the plate, it is obvious that there can be only one other line of equal length, which can be considered as the axis of a similar and isochronous mode of vibration; in these cases it is evident, therefore, that there can only be two superpositions. But in every intermediate direction of an axis, there are three other lines of equal length which constitute axes of similar modes of vibration; and four superpositions can therefore take place whenever the axis of a component mode of vibration is neither a diagonal nor a transverse line.

It would be a tedious and laborious process to ascertain a resultant figure by combining its four component modes of vibration; but the same purpose will be effectually answered by combining them first in pairs, as explained in the

preceding section, and then combining two of these first resultants rectangularly together.

The following process affords great facility for ascertaining the second resultant figure, which arises from the superposition of two first resultants. *a.* and *b.* (fig. 4. page 617,) are the two component first resultants, the similar lines of one being placed rectangularly to those of the other; the vibrating parts are indicated by the letters P and N, according as the vibrations are positive or negative. At C the two figures are superposed, A being represented by the continuous and B by the dotted lines. The surface is now subdivided into a number of unequal rectangles, and by comparing the two component figures together, it is easy to see which of these rectangles are influenced by conspiring, and which by opposing motions; if the motions are found to conspire, the letters P or N must be placed in these rectangles according as the coexisting motions are positive or negative; if the motions are in opposition, a mark may be made to indicate that a quiescent line passes through this rectangle. Wherever a continuous line intersects a dotted line, a mark is to be made, to indicate that a quiescent point is formed; and as in every other part, the quiescent lines of one figure pass over vibrating parts of the other, the boundary lines of all the rectangles must be marked with the letters indicating the motions of the vibrating parts they superpose. The figure C being thus marked, the resultant figure is easily described by joining the fixed points by lines drawn through the rectangles shown to be actuated by opposing motions; carefully avoiding to encroach upon the rectangles of conspiring motion marked P or N.

That the diagonal line is perfectly straight may be proved in the following manner. It must first be premised that the rectangles included within the quiescent lines of each of the first resultant figures, have precisely the same quantity of motion in the same relative points with respect to the surrounding sides, and that the vibrating parts at the edges and corners of the plate must be considered respectively as exact halves and quarters of a complete vibrating part. This being understood, if two similar first resultants be laid alongside each other in the directions in which they are to be superposed, and if a diagonal line be similarly drawn through each of them, it will be obvious that every corresponding point of each line must possess the same intensity of motion. If the successive segments (equal in each figure,) through which the

W. R. U.

lines simultaneously pass, be in opposite states of vibration, they will neutralize each other's effects, and a diagonal quiescent line will be formed; and if they be concurring, all the parts between the coincident or fixed points will be in motion. In the diagram (fig. 4. c.) one diagonal is in the first state and the other in the second.

If the number of lines in the component first resultant figures be uneven, they admit of only one mode of superposition. But first resultants having an even number of quiescent lines, admit of being superposed in two ways, according as they are vibrating in concurrence or in opposition.

It frequently occurs that entire quiescent lines superpose each other; thus, when in the component figure there is an uneven number of lines in each direction, the two rectangular central lines of each superposed figure must coalesce, and consequently they continue in both the resultant figures; examples of this are seen in the resultants of $3|1$, $5|1$, $5|3$, $7|1$, $7|3$, $7|5$, &c. Again, when the number of quiescent lines in one direction of the component figure is three times greater than that in the other, the number of coinciding fixed lines in each direction of the resultant figure is equal to the smallest number in the first resultant, as in $6|2$, $9|3$, $12|4$, $15|5$, &c. See the general Table, page 619—633.

The following general results are obtained from constructing the second resultant figures according to the rules above given.

In superposing first resultants consisting of an even number of lines: 1st, When the number of lines in each direction of the first resultants is even, and the modes of vibration are concurring, no line passes through the centre of the second resultant figure. When the modes of vibration are opposing, two rectangular diagonal lines of compensation occur. 2ndly, When the number of lines in each direction is uneven, and the modes of vibration are concurring, there are always two perpendicular transversal lines passing through the centre; and when the modes are opposing, there are, in addition to these fixed lines, the two diagonal lines of compensation.

When the first resultants consist of an uneven number of lines, in which case there is no distinction of concurring and opposing vibrations, one diagonal line only invariably occurs.

In no case is it necessary to calculate an entire figure. When the number of nodal lines in the primary mode of vibration is even, only one quarter of

the figure is required to be calculated, as it is obvious that every second resultant of this kind consists of four symmetrical, and as it were reflected, portions. But when the primary number of quiescent lines is uneven, it is necessary to calculate one half; the other half is symmetrical and inverted.

Some of the first resultants are never obtained by experiment. When the number of quiescent lines in the primary mode of vibration is uneven, either the first or the second resultant may be obtained at pleasure; thus in $3\frac{1}{2}$ if the impulses be made at a corner, where the motion of both superpositions is at its maximum, the second resultant must arise; but if they be made at the middle of a side, the first resultant only will appear, because the point of excitation is a quiescent point of the other. But in all cases where there is an *even* number of lines, it is impossible to obtain the first resultant, because each maximum of vibration equally belongs to both superpositions.

§ 6.

I have given in pages 619—633, a Table which shows every perfect resultant figure of a square surface when the number of quiescent lines in the primary modes of vibration does not exceed twelve. I have carefully calculated each figure by the rules laid down in the preceding sections, and have shown in the Table the successive processes of superposition. The first vertical row exhibits the two primary modes of vibration superposed at the required angles; one figure being represented by the continuous lines, and the other by the dotted lines. The second row contains the first resultants which arise from the opposing superpositions of the preceding; and the third row, those which result from their concurring superpositions. The fourth and fifth rows exhibit the perfect second resultants which are formed, the former by the opposing and the latter by the concurring superpositions of the first resultant which the plate has been already found competent to produce.

On comparing the calculated figures with those obtained experimentally by CHLADNI, the greater number are found exactly to agree; there are, however, some differences which it will be necessary to explain. In the first place, there is an obvious cause of error in delineating figures from experiment, from this circumstance,—that the sand accumulates in the spaces where two convex curves are near and opposite to each other, the motion being there very small, so that it is difficult to ascertain whether the curves join, or not. Secondly,

Inequalities in the plate will sometimes occasion lines which ought to intersect each other, so as to appear separated curves. On comparing together the figures CHLADNI has marked as $6\frac{1}{4}$, $6\frac{1}{4}$, $7\frac{1}{2}$, $7\frac{1}{4}$, $8\frac{1}{3}$ c. &c. with those of the calculated Table, they will be found to differ only in these respects.

Another cause of difference is this: When the lines of one component figure very nearly coincide with those of the other, but without actually doing so, the resultant figure may be such as would arise from their actual superposition, instead of that which accurate calculation would give. In CHLADNI's Table there are two instances of this alteration, $7\frac{1}{2}a$. and $8\frac{1}{3}a$.

A few of the figures delineated by CHLADNI are irregular resultants formed by the superpositions of dissimilar modes of vibration. These irregular resultants can be formed only when the dissimilar component modes of vibration give the same sound, and have a maximum point of vibration in common, at which they can be simultaneously excited. The figure marked by CHLADNI $6\frac{1}{4}$, I find to be an irregular resultant formed by the combination of $6\frac{1}{4}$ with $3\frac{1}{5}$, which both give the same sound C^4 . The irregular figure marked in his Table $5\frac{1}{4}a$. is a compound of $5\frac{1}{4}$ and $2\frac{1}{5}$.

The calculated figures $6\frac{1}{4}$, $7\frac{1}{4}$, $8\frac{1}{4}$, $9\frac{1}{4}$, $10\frac{1}{4}$, $10\frac{1}{2}$, and $11\frac{1}{4}$, are not to be found in CHLADNI's Table. The near approach of the inclined lines of their primary component figures to parallelism is the cause of the great difficulty in obtaining these figures by experiment.

The figures marked by CHLADNI $10\frac{1}{3}$, $9\frac{1}{4}$, $8\frac{1}{5}$, $7\frac{1}{6}$, $10\frac{1}{4}$, $9\frac{1}{5}$, $8\frac{1}{6}$, and $9\frac{1}{7}$, exceed the limits within which I have calculated the Table, and are therefore not to be found in it.

§ 7. *Imperfect resultant Figures.*

I have hitherto considered those resultant figures only which arise from the superpositions of similar modes of vibration, each exactly equal in intensity; these I shall in future call *perfect* resultant figures. But when the vibrations of the superposed modes are unequal in intensity, then a figure intermediate between the perfect resultant and one of its components is formed; these intermediate figures I shall call *imperfect* resultants. They are experimentally obtained by varying in a slight degree the places at which the plate is held or touched, from those necessary to determine the corresponding perfect resultant figure; the place at which the bow is applied remaining in both cases the same.

Fig. 6. *a. b. c. d. e.* in CHLADNI's Table, page 611, represents the successive

transformations of figure which take place when each component mode of vibration presents three transversal lines : *a.* and *e.* are the two components ; *c.* the perfect resultant ; *b.* an imperfect resultant, in which the excursions of *a.* are the greatest : and *d.* an imperfect resultant, in which *e.* has the greatest energy.

Fig. 11. *a. b.* page 611, exhibits the transitions of the opposing superposition of two primary figures, each presenting four transversal lines ; and fig. 12. *a.* and *b.* the changes of the concurring superposition of the same.

These are the principal types of the transformation of primary figures into first resultants. In each of these series of transitions there are certain points which are invariable during every change : these are, the quiescent points formed by the nodal lines of one figure intersecting those of the other, and the centres of vibration where the maxima of positive or negative vibration agree in each component mode of vibration. The points of compensation are changeable.

Figs. 29. *a.* and 30. *a.* page 613, represent imperfect second resultants, formed by two superpositions of the first resultant figure 6|2. Fig. 29. *a.* arises from concurring, and fig. 30. *a.* from opposing superpositions. The straight lines in these imperfect figures arise from the coincidence of entire quiescent lines in each component figure, and, consequently, they remain unaltered whatever may be the relative intensities of the superposed modes of vibration. But the curved lines, which are formed of compensating points, change with the varying intensities.

§ 8. *Figures of irregular Plates.*

If the sides of the square be nearly, but not exactly, equal, the superpositions of two similar modes of vibration with transversal lines still take place ; but instead of exhibiting perfect resultants, figures resembling transitional figures appear. Thus in the binary superposition (page 611, fig. 1.) of the figure with two transversal lines, if the sides be unequal, the crossed lines separate at their point of intersection and are converted into two curves, the summits of which recede from each other as the difference in the lengths of the sides becomes greater.

Also, if the diagonals of the square be unequal, the resultant figure (page 611, fig. 2.) arising from two superposed modes of vibration with diagonal axes, will be modified in a similar manner.

Corresponding modifications are occasioned, through accidental differences of elasticity, &c. in the directions of the axes of the superposed modes of vibration, even when the dimensions of the plate are apparently equal.

If a plate of glass be covered on one of its sides with leaf-gold, or if a plate of ground glass be substituted for an ordinary glass plate with smooth surfaces, the figures may be obtained distinctly delineated by lines consisting of a single row of grains of sand. Experiments made in this manner, upon square plates carefully prepared, induced Professor STREHLKE to conclude, after many minute measurements of these lines, that all acoustic figures are formed of hyperbolic curves, and that the quiescent lines never intersect each other. But however correct these experiments may have been, the conclusions drawn from them are unwarranted; were it possible to obtain plates of a perfectly homogeneous substance, and of accurately equal dimensions, there can be no doubt that the lines, however finely defined, would actually intersect each other.

§ 9.

I have already, § 1., given CHLADNI's Table of the comparative sounds, and numbers of vibrations of the figures of square surfaces obtained from experiment. In the following Table these results are arranged so as to correspond with the views taken in this paper. The numbers in the first vertical row indicate the number of parallel quiescent lines in the primary figure. In the horizontal rows the angles at which the lines of the primary modes of vibration intersect each other are shown; and the figures between brackets give the notation of the first resultant produced by their superposition; below these its number of vibrations, and the character representing its musical sound, are given; when there are two of these lower lines separated by a horizontal dash, the one above indicates the sound of the opposing superposition, and that below it the concurring superposition.

Thus it appears, that every figure of a square surface which experiment can give, may be reduced to a primary figure with parallel lines, giving the same sound: if, therefore, the analytical investigation be confined to these, many of the difficulties will disappear. EULER has investigated the subject when lines parallel to a side only are concerned; it remains to extend the inquiry to modes of vibration the nodal lines of which are perpendicular to any line passing through the centre of the surface. An analytical expression for all the sounds of a square plate may probably be obtained, which shall be a function of the number of quiescent lines, and the length of the axis of the mode of vibration.

TABLE.

2	90° (111) G, 6	180° (210) D—, 9 E..F, 10+					
3	126° 52' (211) B, 15	180° (310) G ¹¹ , 25					
4	90° (212) A..B, 27+.28—	143° 8' (311) B, 30 C ³ +, 32?.33.?	180° (40) G ¹¹ —, 49— G ¹¹ , 50				
5	112° 38' (312) F ¹¹ , 45	151° 56' (411) B ³ —, 55..56—	180° (510) E ³ +, 81				
6	90° (313) C ³ +, 64.65	126° 52' (42) C ¹¹ , 70 D ³ , 72	157° 22' (511) F ³ , 84 F ¹¹ , 90.91	180° (610) B ³ , 120..121 C ⁴ —, 125..126			
7	106° 16' (413) F ¹¹ , 90..91	136° 22' (512) G ¹¹ , 98.99.100—	161° 4' (611) C ⁴ , 128	180° (710) F ⁴ , 169			
8	90° (44) B ¹¹ —, 110+.112	118° 4' (513) B ³ , 119.120 C ⁴ , 125.126.128—	143° 8' (62) C ¹¹ , 135.140 D ⁴ , 144	163° 44' (711) F ⁴ ..F ¹¹ , 175.? 180.? 180° (80) B ¹¹ , 224.225 B ⁴ +225+231.?			
9	102° 40' (514) D ¹¹ , 150.153	126° 52' (613) E ⁴ , 160.162	148° 6' (712) F ¹¹ +.180+.? 189—	165° 44' (811) 180° (910) D ³ , 289			
10	90° (515) F ¹¹ , 180	112° 38' (614) G ⁴ , 189..192 G ¹¹ , 196.198.200—	133° 26' (713) G ¹¹ +.209.210 A ⁴ , 216.220	151° 56' (82) B ⁴ , 240.242 C ³ — 245.250	167° 18' (911) unascertained. 180° (1010)		
11	100° 24' (615) B ¹¹ , 224+.231—	120° 30' (714) B ⁴ , 240.242	138° 52' (813) C ³ +, 256+.264—	154° 56' (92) E ³ — 315	168° 34' (101) 180° (1110)		
12	90° (616) C ³ , 256+.264—	108° 56' (715) C ¹¹ , 275.280 D ³ , 286.288	156° 52' (814) D ³ , 286.288 D ¹¹ , 294.299	143° 8' (913) F ³ , 330.336 F ³ +343, 345	157° 22' (1012) 169° 36' (1111) 180° (1210)		

§ 10.

Immediately after the publication of CHLADNI's experiments on square plates, JAMES BERNOUILLI attempted to demonstrate them analytically; but his investigation was entirely unsuccessful; his conclusions were founded on erroneous data, and the results he obtained were at variance with experiment. His assumptions were these: that the primary figures consisted of 2, 3, 4, 5, 6, 7, &c. lines parallel to the side only, these being the modes of vibration of a lamina as investigated by EULER; that any two similar or dissimilar modes of vibration might superpose each other rectangulary, the nodal lines of the two components appearing together in the resultant mode of vibration; and that the sound of the resultant differed from that of either of the two components, being much higher. The figures given by experiment he considered accidental distortions of these compound figures. This theory gave no account of those figures in which a single line in one direction coexists with any number in the other, as there is no primary figure consisting of one nodal line only; and BERNOUILLI acknowledged his theory to be imperfect in this respect.

The failure of BERNOUILLI led CHLADNI inconsiderately to state, that "the supposition of regarding such a rigid membraniform body as a network formed by curved lines in one direction applied upon curved lines in another direction, is not conformable to nature, and will never give, either results agreeing with experiment, or an appearance of explanation of some of the most simple vibrations." That this assertion is erroneous, the considerations in the present paper have, I conceive, fully proved. The error of BERNOUILLI did not consist in assuming that the observed acoustic figures were formed by superposing simple modes of vibration on each other, for this has been shown to be true; but in his assumptions of the manner in which these superpositions were made, and the effects which resulted from such hypothetical superpositions.

The various mathematicians who have more recently undertaken to investigate the laws of vibrating surfaces, as POISSON, CAUCHY, Mademoiselle GERMAIN, &c., do not appear to have taken into consideration anything resembling the theory of superposition.

Dr. YOUNG seems to have had a correct notion of the origin of the acoustic figures; for in his Lectures, when slightly noticing CHLADNI's experiments, he remarks, "The vibrations of plates differ from those of rods in the same man-

ner as the vibrations of membranes differ from those of chords, the vibrations which cause the plate to bend in different directions being combined with each other, and sometimes occasioning singular modifications."

The brothers WEBER, in their excellent work the *Wellenlehre*, published in 1825, have advanced a step nearer the truth than any of their predecessors. They have shown, that in a square vessel containing water or mercury, two series of stationary waves, one parallel to each side, may be made to intersect each other; and that the compound wave formed by their interferences assumes the form shown in § 3. to be the resultant of two superpositions of parallel transverse lines. Their observations are confined to those modes of undulation, analogous to the first resultants of primary modes of vibration with lines parallel to a side. Though I had advanced considerably in the present inquiry before I saw this work, yet I should be wanting in justice to these philosophers did I not here state that theirs is the merit of having shown, in the most simple case, the way in which the superpositions of modes of vibration or undulation actually do take place.

§ 11. *Plates of Wood.*

From the rules already laid down, it is obvious that the series of figures presented by a square plate of any homogeneous material ought not to be obtained on a square plate of wood, in which substance the elasticity is not the same in all directions. If a square plate of wood be prepared with its fibres parallel to one of the sides of the square, the axes of greatest and least elasticity will be disposed rectangularly, and parallel to the adjacent sides; in this case the same primary mode of vibration in the two directions will not give the same sound, although the dimensions of the vibrating parts are the same in both; consequently they cannot coexist, and the resultant figures with diagonal lines will be wanting on such a plate. But if the axes of the two component modes of vibration be equally inclined to either of the axes of elasticity, these modes of vibration will be necessarily similar and isochronous, and therefore capable of superposition; on a square plate of wood, consequently, all those first resultants which consist of any number of lines parallel to the sides intersecting each other rectangularly, may be obtained; and the same figure will be accompanied by different sounds, according as the axes

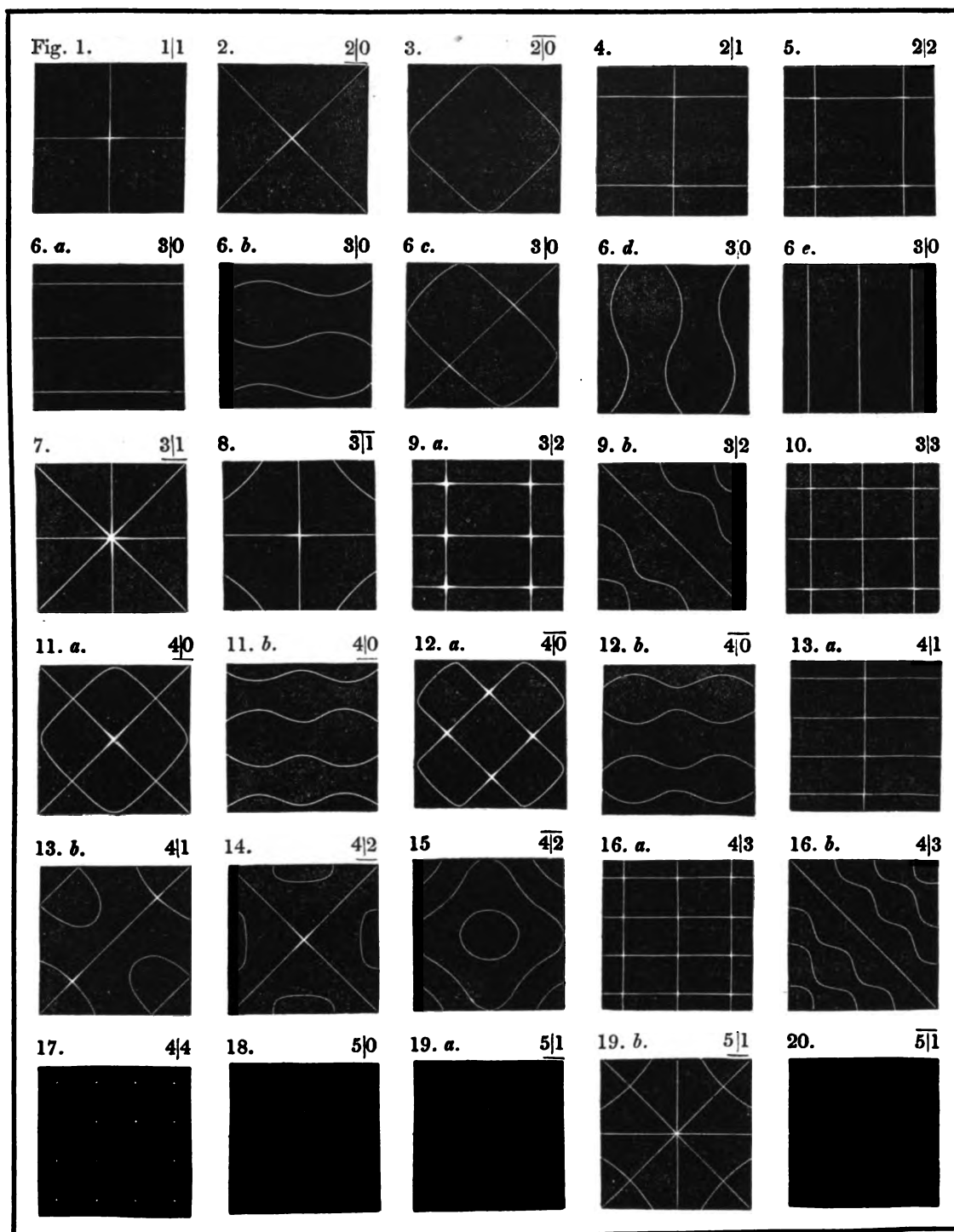
of the modes of vibration are inclined to the axes of least or greatest elasticity. It is easy to foresee that none of the second resultants, which consist of four isochronous superpositions, can be obtained on such a plate.

But if the wooden plate, instead of being square, be a rectangle, the sides of which are inversely as the squares of their resistance to flexion, the two modes of vibration parallel to the sides, though differing in length, will be isochronous; and their coexistence will give rise to a resultant figure with lines parallel to the diagonal. Thus on a rectangular plate of straight-fibred deal wood, in which the proportion of the sides were as 28 to 59, I obtained the two crossing diagonal lines, corresponding to the second figure of a homogeneous square plate of glass or metal.

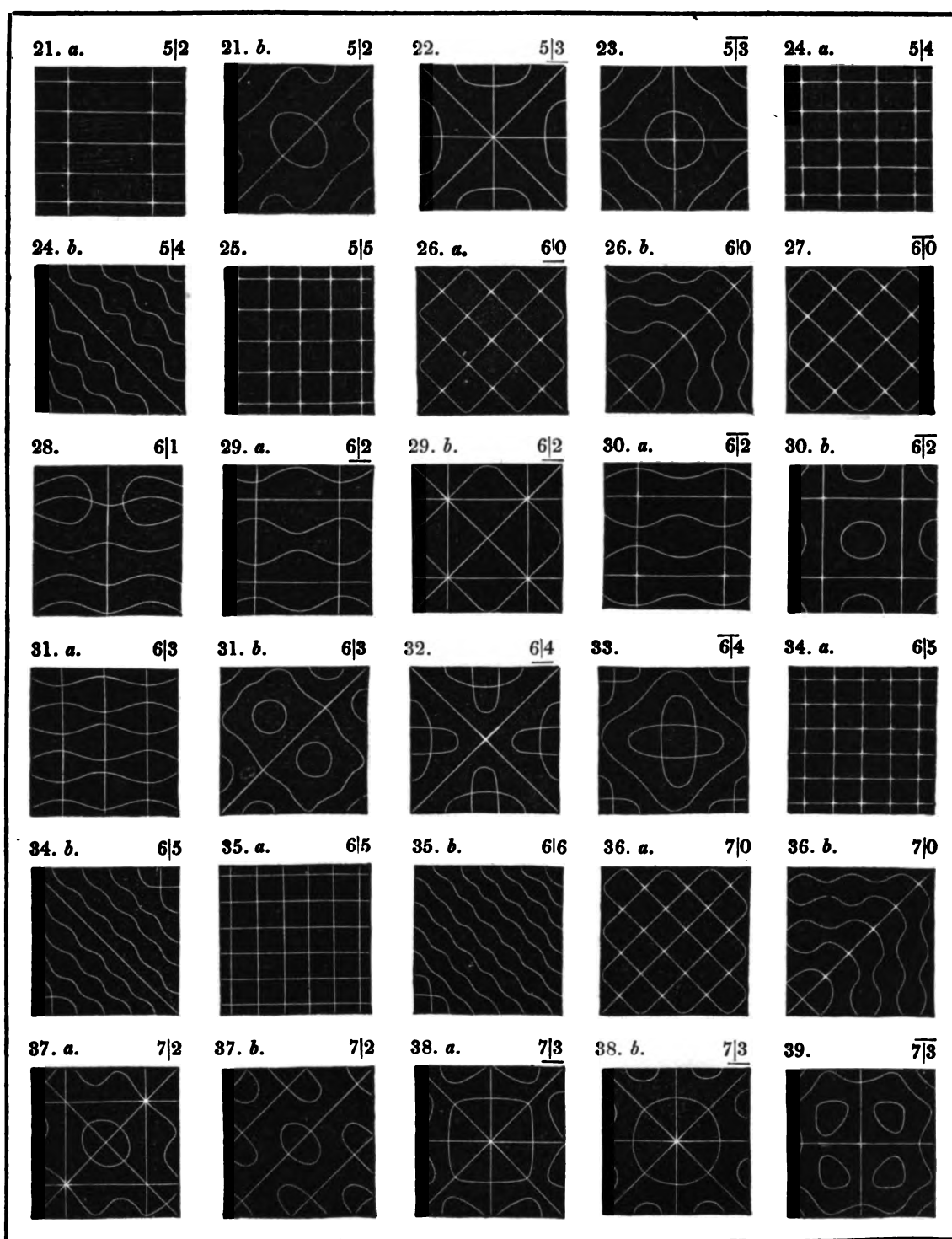
SAVART has made a series of numerous and accurate experiments on the changes which take place in the sound, and also in the form and position of the figure of the first mode of vibration on circular plates of wood of similar dimensions, cut in different directions with respect to the three principal axes of elasticity. All the results he has obtained are in perfect accordance with the rules stated in this paper, and might have been predicted by them. He has extended his investigations to circular slices of crystals, cut in various directions with respect to their axes, and has obtained in this way much valuable information. These researches of SAVART point out a new direction to our inquiries respecting the structure of bodies; and the utility of his experiments will be greatly enhanced by the knowledge we now possess of the causes on which these phenomena depend. I shall shortly return to this subject.

CHLADNI'S TABLE

Of the figures of square surfaces, obtained by experiment.



(Continuation of CHLADNI'S TABLE.)



(Continuation of CHLADNI's TABLE.)

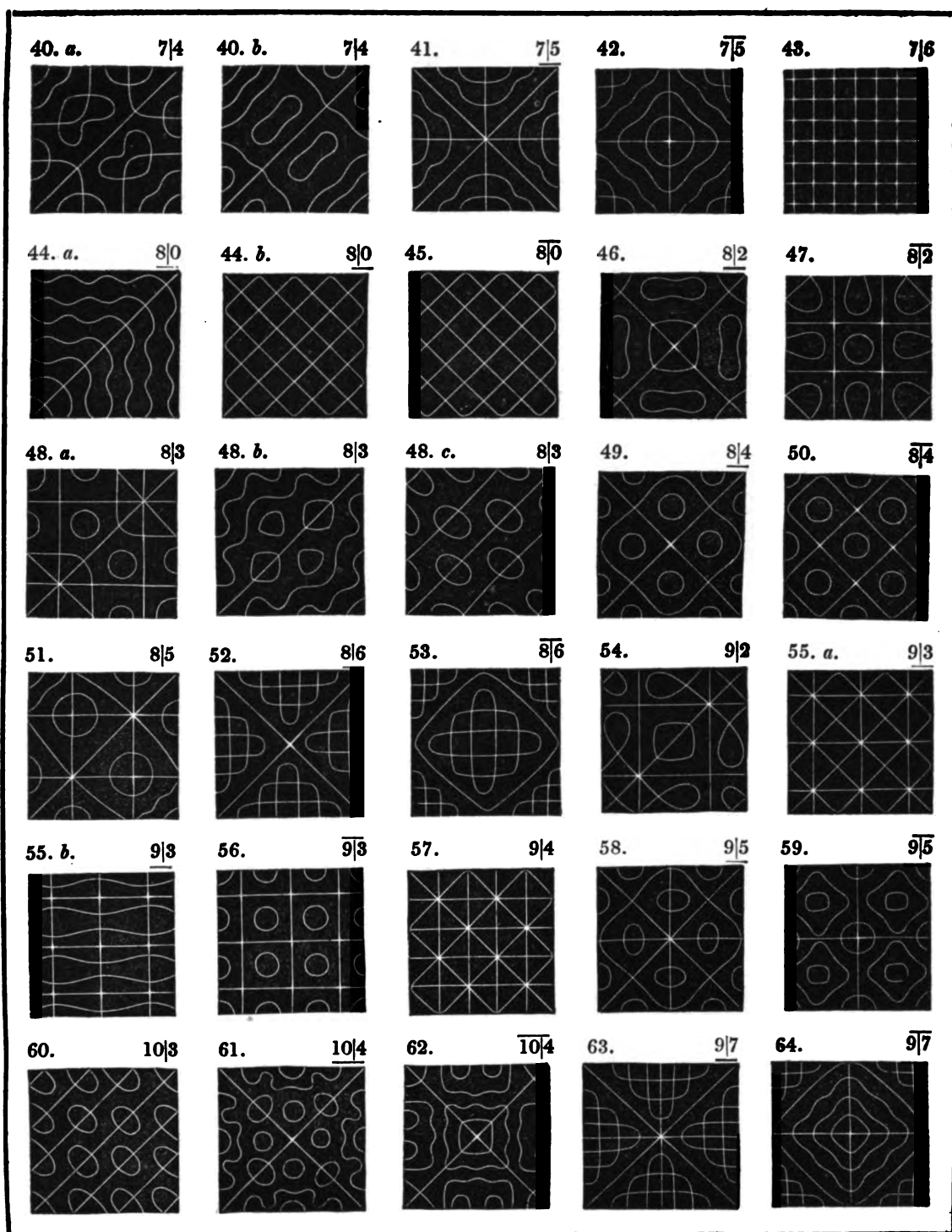


Fig. 1.

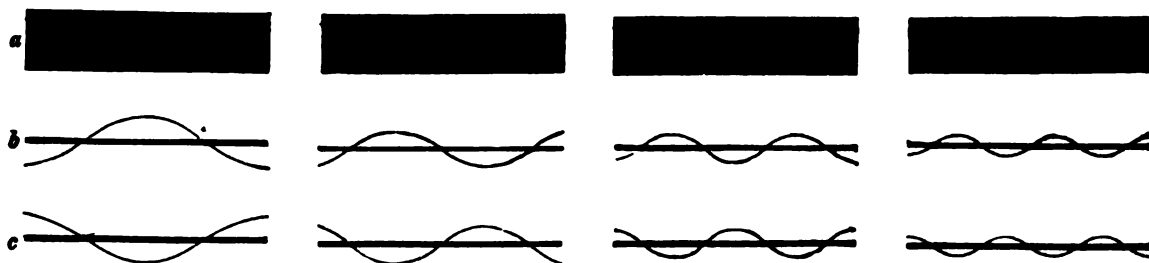


Fig. 2.

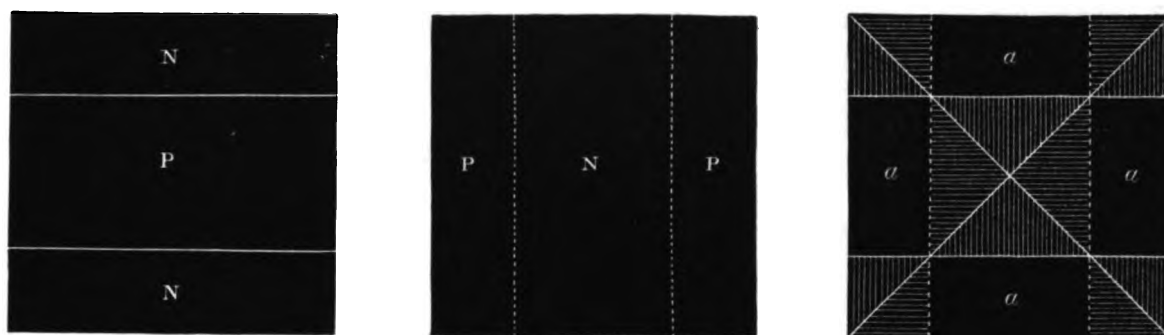


Fig. 3.

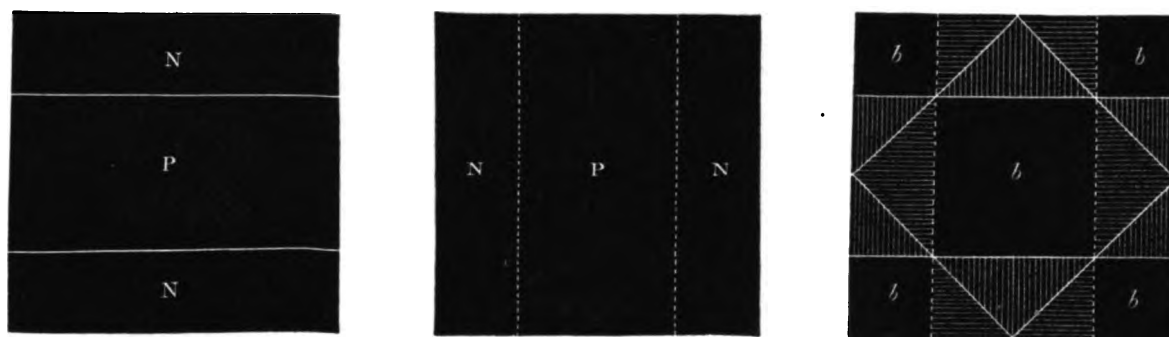
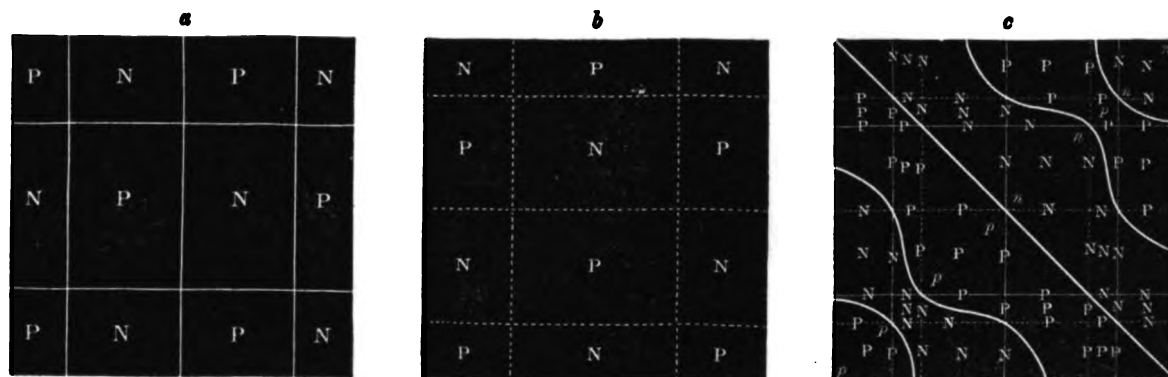


Fig. 4.



[111]

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

111

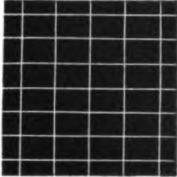
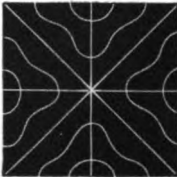
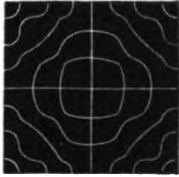
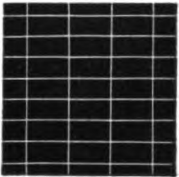
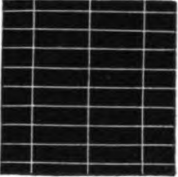
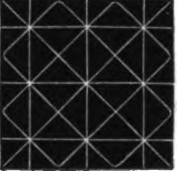
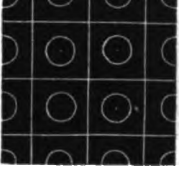
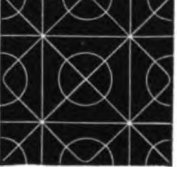
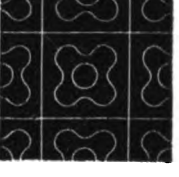
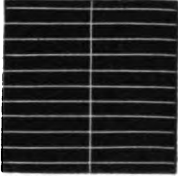
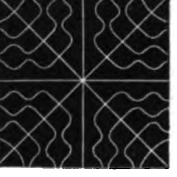
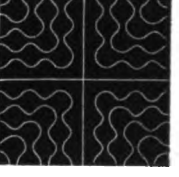
111

TABULAR VIEW

Of all the figures of a square plate, determined by calculation to result from two or four superpositions, when the quiescent lines of the primary figures do not exceed twelve in number.

	Primary Figures, showing the angles at which they are su- perposed to form the first resultants. 90°	First Resultants, formed by two superpositions.		Second Resultants, formed by four superpositions.	
		Opposing.	Concurring.	Opposing.	Concurring.
II.					
	180° 				
III.	126° 52' 	1/2 			
	180° 				
IV.	90° 		2/2 		

TABLE of Calculated Figures.—(Continued.)

Primary Figures, showing the angles at which they are su- perposed to form the first resultants. 108° 56'	First Resultants, formed by two superpositions.		Second Resultants, formed by four superpositions.	
	Opposing.	Concurring.	Opposing.	Concurring.
	5 7 			
126° 52'		4 8 		
143° 8'	3 9 			
157° 22'		2 10 		
169° 36'	1 11 			
180° 				

XXVI. *On the Reflex Function of the Medulla Oblongata and Medulla Spinalis.* By MARSHALL HALL, M.D., F.R.S. L. & E., &c. &c.

Received June 11,—Read June 20, 1833.

1. *Introduction.*

THE higher departments of every science are doubtless its general principles and its laws. These have a claim to our consideration beyond that of insulated facts or mere details. Impressed with this truth, I have hitherto devoted my attention chiefly to the laws and principles of physiology. In a former memoir*, I gave the outline of one of the most general of the laws of this science,—that of the inverse ratio of the respiration and of the irritability. In the present memoir, I propose to give an account of a principle of action in the animal economy, which has not hitherto, I think, been distinguished with sufficient precision from the other vital and animal functions.

The principle to which I have adverted is connected, in a peculiar manner, with the medulla oblongata and the medulla spinalis. There is still much discrepancy of opinion amongst physiologists, in regard to the properties and functions of these parts of the nervous system. LEGALLOIS concluded, from his interesting series of experiments, that the spinal marrow, as a whole, and in distinct portions, is the exclusive source of sensation and voluntary motion. He observes†, “La vie du tronc dépend de la moëlle épinière, et celle de chaque partie dépend spécialement de la portion de cette moëlle dont elle reçoit ses nerfs. De plus, il est facile de démontrer que cette prérogative de la moëlle épinière, d’être la source du sentiment et de tous les mouvemens volontaires du tronc, lui appartient exclusivement à tout autre organe.” The Reporters of the Institute adopt the conclusions of LEGALLOIS: “M. LEGALLOIS,” they observe‡, “a démontré que la section de la moëlle épinière sur les

* Philosophical Transactions for 1832.

† Œuvres de LEGALLOIS, Paris 1824, tome i. p. 62.

‡ Ibid. p. 251.

premières ou sur les dernières vertèbres cervicales, n'arrête que les mouvemens inspiratoires, et qu'elle laisse subsister dans tout le corps le sentiment et les mouvemens volontaires. Cette distinction est capitale : personne ne l'avait faite avant lui*." M. CRUVEILHIER, on the other hand, denounces this view of the functions of the spinal marrow as one of the errors of modern physiology. He observes†, "L'indépendance des diverses parties de la moëlle les unes des autres, l'indépendance de la moëlle du cerveau, assez généralement admise dans ces derniers temps, me paraît une grave erreur physiologique fondée sur d'ingénieuses expériences. L'opinion des anciens, qui regardaient la moëlle comme un gros cordon nerveux destiné à répondre lui seul à tous les nerfs de l'économie, pour transmettre en définitive au cerveau les impressions, ou pour en recevoir les impulsions volontaires ou organiques, cette opinion est bien plus en harmonie avec les faits, avec la grande loi anatomique de la continuité du système nerveux."

It will not be difficult to prove that the conclusions of LEGALLOIS and the Reporters of the Institute, are not legitimate deductions from the facts before them. But M. CRUVEILHIER altogether overlooks these facts, which are amongst the most interesting in physiology, and adopts an opinion which, however true, is far too exclusive.

On the more recent occasion of a report upon the admirable work of M. FLOURENS, the Perpetual Secretary of the Institute states his opinion on this point in a manner far more problematical. "L'auteur," he observes, "conclut que la sensation et la contraction n'appartiennent plus à la moëlle épinière qu'aux nerfs ; et cette conclusion est certaine pour les animaux entiers. Ce serait une grande question de savoir si elle l'est également pour les animaux qui ont perdu leur encéphale, et qui, dans certaines classes, paraissent loin de perdre sur-le-champ leurs fonctions animales‡."

* More recently, M. MAGENDIE, M. LALLEMAND, and M. OLLIVIER have repeated the same opinion: *Anatomie des Systèmes Nerveux*, par A. DESMOULINS, Paris 1825, p. 561, &c.; *Observations Pathologiques propres à éclairer la Physiologie*, ed. 2, Paris 1825, pp. 88, 96, &c.; *Traité de la Moëlle Épinière*, ed. 2, Paris 1827, p. 17, &c. The subject is unnoticed by M. SERRES: *Anatomie Comparée du Cerveau*, Paris 1824. The physiologists of our own country have adopted the same views: Philip on the Vital Functions, ed. 3, p. 120; MAYO's admirable *Outlines of Human Physiology*, ed. 3, p. 227-231, &c.

† *Anatomie Pathologique*, Fasc. III.

‡ *Du Système Nerveux*, par P. FLOURENS, Paris 1824, p. 70.

It was a singular mistake to imagine that the same conclusion could be just in reference to the entire animal, which was incorrect in reference to the animal deprived of its encephalon. The facts are these: in the entire animal, sensation and voluntary motion, functions of the cerebrum, combine with the functions of the medulla oblongata and medulla spinalis, and may therefore render it difficult or impossible to determine those which are peculiar to each; if, in an animal deprived of the brain, the spinal marrow, or the nerves supplying the muscles, be stimulated, those muscles, whether voluntary or respiratory, are equally thrown into contraction, and, it may be added, equally in the complete and in the mutilated animal; and, in the case of the nerves, equally in limbs connected with and detached from the spinal marrow.

The operation of all these various causes of muscular contraction may be designated *centric*, as taking place *at*, or at least in a direction *from*, central parts of the nervous system. But there is another function the phenomena of which are of a totally different order and obey totally different laws, being excited by causes in a situation which is *eccentric* in the nervous system, that is, distant from the nervous centres. This mode of action has not, I think, been hitherto distinctly understood by physiologists. It is involved in the question which Baron CUVIER considers as so full of interest, and is that treated of in the following pages.

Many of the phenomena of this principle of action, as they occur in the limbs, have certainly been observed. But, in the first place, this function is by no means confined to the limbs: for, whilst it imparts to each muscle its appropriate tone, and to each system of muscles its appropriate equilibrium or balance, it performs the still more important office of presiding over the orifices and terminations of each of the internal canals in the animal economy, giving to them their due form and action; and, in the second place, in the instances in which the phenomena of this function have been noticed, they have been confounded, as I have stated, with those of sensation and volition; or, if they have been distinguished from these, they have been too indefinitely denominated instinctive, or automatic. I have been compelled, therefore, to adopt some new designation for them, and I shall now give the reasons for my choice of that which is given in the title of this paper.

This property is characterized by being *excited* in its action, and *reflex* in its

course : in every instance in which it is exerted, an impression made upon the extremities of certain nerves is conveyed to the medulla oblongata or the medulla spinalis, and is reflected along other nerves to parts adjacent to, or remote from, that which has received the impression.

It is by this reflex character that the function to which I have alluded is to be distinguished from every other. There are, in the animal economy, four modes of muscular action, of muscular contraction. The *first* is that designated *voluntary*: volition, originating in the cerebrum, and spontaneous in its acts, extends its influence along the spinal marrow and the motor nerves, in a *direct line*, to the voluntary muscles. The *second* is that of the *respiration*: like volition, the motive influence in respiration passes in a *direct line* from one point of the nervous system to certain muscles ; but as voluntary motion seems to originate in the cerebrum, so the respiratory motions originate in the medulla oblongata: like the voluntary motions, the motions of respiration are spontaneous ; they continue, at least, after the eighth pair of nerves has been divided. The *third* kind of muscular action in the animal economy is that termed *involuntary*: it depends upon the principle of irritability, and requires the *immediate* application of a stimulus to the nervo-muscular fibre itself. These three kinds of muscular motion are well known to physiologists ; and I believe they are all which have been hitherto pointed out. There is, however, a *fourth*, which subsists, in part, after the voluntary and respiratory motions have ceased, by the removal of the cerebrum and medulla oblongata, and which is attached to the medulla spinalis, ceasing itself when this is removed, and leaving the irritability undiminished. In this kind of muscular motion, the motive influence does not originate in any central part of the nervous system, but at a distance from that centre: it is neither spontaneous in its action, nor direct in its course ; it is, on the contrary, *excited* by the application of appropriate stimuli, which are not, however, applied immediately to the muscular or nervo-muscular fibre, but to certain membranous parts, whence the impression is carried to the medulla, *reflected*, and reconducted to the part impressed, or conducted to a part remote from it, in which muscular contraction is effected.

The first three modes of muscular action are known only by actual movements or muscular contractions. But the reflex function exists as a continuous muscular action, as a power presiding over organs not actually in a state of

motion, preserving in some, as the glottis, an open *, in others, as the sphincters, a closed form, and in the limbs, a due degree of equilibrium, or balanced muscular action,—a function, not, I think, hitherto recognised by physiologists.

The three kinds of muscular motion hitherto known may be distinguished in another way. The muscles of voluntary motion and of respiration may be excited by stimulating the nerves which supply them, in any part of their course, whether at their source, as a part of the medulla oblongata or medulla spinalis, or exterior to the spinal canal: the muscles of involuntary motion are chiefly excited by the actual contact of stimuli. In the case of the reflex function alone, the muscles are excited by a stimulus acting mediately and indirectly in a curved and reflex course, along superficial sub-cutaneous or sub-mucous nerves proceeding to the medulla, and muscular nerves proceeding from the medulla. The first three of these causes of muscular motion may act on detached limbs or muscles. The last requires the connexion with the medulla to be preserved entire.

All the kinds of muscular motion may be unduly excited. But the reflex function is peculiar in being excitable into modes of action not previously subsisting in the animal economy, as in the cases of sneezing, coughing, vomiting, &c. The reflex function also admits of being permanently diminished or augmented, and of taking on some other morbid forms, of which I shall treat hereafter.

I shall thus have occasion to speak of the reflex function as the source of equilibrium in the muscular system; as excitable into various actions, which, however familiar, are not constant; and as assuming morbid forms.

Before I proceed to the detail of the experiments upon which this disquisition rests, it may be well to point out several instances in illustration of the various sources and modes of muscular action which have been enumerated. None can be more familiar than the act of swallowing. Yet how complicated is this act! The apprehension of the food by the teeth, the tongue, &c., is voluntary, and cannot, therefore, take place in an animal from which the cerebrum is removed †. The transition of the food over the glottis and along the middle and lower parts of the pharynx depends upon the reflex function: it can take

* See LEGALLOIS, *Op. cit.* p. 176—178.

† Du *Système Nerveux*, par M. FLOURENS, Paris 1824, p. 90.

place in animals from which the cerebrum has been removed*, or the ninth pair of nerves divided†; but it requires the connexion with the medulla oblongata to be preserved entire‡; and the actual contact of some substance which may act as a stimulus§: it is attended by the accurate closure of the glottis, and by the contraction of the pharynx. The completion of the act of deglutition is dependent upon the stimulus immediately impressed upon the muscular fibres of the œsophagus, and is the result of excited irritability.

The example which I have given is one of excited reflex function. The condition of the glottis during respiration, and that of the pharynx and of the sphincters at all times, except during the acts of deglutition, or of excretion, afford equally interesting and familiar examples of the permanent influence of that function. Whilst the nervous connexion between the larynx and the medulla oblongata is preserved entire,—in the rabbit (*Lepus cuniculus*), for example,—the glottis is preserved open, being slightly dilated during each act of inspiration; but if the superior laryngeal nerves be divided, the aperture immediately becomes so much diminished, that a state of excessive dyspnœa is induced. The sphincter ani, on the other hand, remains closed in the decapitated turtle (*Chelonia mydas*), if the lower part of the medulla spinalis be left in its canal; but it becomes immediately relaxed and open, if this part of the nervous system be withdrawn. The action of this muscle depends upon the medulla spinalis, and not upon the brain only.

However plain these observations may have made the fact, that there is a function of the nervous and muscular system distinct from sensation, from the voluntary and respiratory motions, and from irritability, it is right, in every such inquiry as the present, that the statements and reasonings should be made with the experiment, as it were, actually before us. It has already been remarked, that the voluntary and respiratory motions are spontaneous acts, not necessarily re-

* Du Système Nerveux, par M. FLOURENS, Paris 1824, p. 90.

† The Nervous System, by CHARLES BELL, F.R.S. 4to ed. 1830. Appendix, p. cxviii.

‡ De l'Usage de l'Epiglote, par M. MAGENDIE, Paris 1813, pp. 6, 23, &c.

§ This is the reason of our inability to perform the act of swallowing two or three times in rapid succession, without taking something into the mouth, or allowing time for the secretion of a portion of saliva. The reflex function must be excited into action by the contact of a stimulus. The act of swallowing cannot, therefore, be renewed unless some substance, as saliva, be carried into contact with the pharynx. See further, p. 661.

quiring the agency of a stimulus. If, then, an animal can be placed in such circumstances that such motions will certainly not take place, the power of moving remaining, it may be concluded that volition and the motive influence of respiration are annihilated. Now this is effected by removing the cerebrum and the medulla oblongata. These facts are fully proved by the experiments of LEGALLOIS and M. FLOURENS, and by several which I proceed to detail, for the sake of the opportunity afforded by doing so, of stating the argument most clearly.

I divided the spinal marrow of a very lively snake (*Coluber natrix*), between the second and third vertebræ. The movements of the animal were, immediately before, extremely vigorous and unintermitted. From the moment of the division of the spinal marrow, it lay perfectly tranquil and motionless, with the exception of occasional gaspings and slight movements of the head.

It became quite obvious that this state of quiescence would continue indefinitely, were the animal secured from all external impressions.

Being now stimulated, the body began to move with great activity, and continued to do so for a considerable time, each change of position or situation bringing some fresh part of the surface of the animal into contact with the table or other objects, and renewing the application of stimulus.

At length the animal became again quiescent; and being carefully protected from all external impressions, it moved no more, but died in the precise position and form which it had last assumed.

It requires a little manœuvre to perform this experiment successfully: the motions of the animal must be watched, and slowly and cautiously arrested by opposing some soft substance, as a glove or cotton wool; they are by this means gradually lulled into quiescence. If at this moment the figure last assumed be sketched upon paper, and the animal be left, protected from external impressions, it will be found to retain the same identical form when all vitality has ceased.

The slightest touch with a hard substance, the slightest stimulus, will, on the other hand, renew the movements of the animal in an active form. But that this phenomenon does not depend upon sensation, is further fully proved by the facts, that the position last assumed, and the stimuli applied, may be such as would be attended by extreme or continued pain, if the sensibility were undestroyed: in one case the animal remained partially suspended over the acute

edge of the table ; in others the infliction of punctures, and the application of a lighted taper, did not prevent the animal, still possessed of active powers of motion, from passing into a state of complete and permanent quiescence.

The same observations were made upon various other animals—the turtle, the viper (*Vipera Berus*), the toad (*Bufo vulgaris*), the frog (*Rana temporaria*), the eft (*Triton cristatus*), &c. It may therefore be stated as a general fact, that if an animal be deprived of the cerebrum and medulla oblongata, and placed under an inverted bell-glass, or otherwise protected from external stimuli, it will not move, however easily it may be excited to motion by external impressions.

I must now solicit the attention of the Society to three important points : it is obvious,

1st, That sensation can act, in inducing muscular motion, only through the medium of volition ;

2ndly, That, in the experiments which have been described, volition,—the *will*, and not the *power*, to move, was annihilated ;

3rdly, That, in such cases,—volition being destroyed and the agency of sensation excluded,—the influence of external impressions, which might be supposed to induce pain, must have been exerted upon some property of the nervous system different from sensibility.

The absence of spontaneous motions in decapitated animals, proves the privation of volition ; and the privation of volition removes all evidence of sensibility in excited motions, and indeed positively excludes its influence. Sensation, volition, and motion, may be viewed as three links of the chain, in the case in which motion is induced by pain. If the second link be destroyed, the *connexion* between the first and third is dissolved. The proof, in fine, that the excited motions which belong to the reflex function are independent of sensation, is precisely of the same character as that by which the motions due to irritability are distinguished from the same principle.

We are hence led to the conclusion that the excited motions of decapitated animals are dependent upon a principle different from sensation and volition ; and we are further led to the inquiry—What is the nature of that principle—what the cause of those motions, which remain after sensation and volition are destroyed ?

But before I enter upon this question, it is important to show still more distinctly than I have done, the distinction between the movements arising from the reflex function of the medulla oblongata and medulla spinalis, and those arising from irritability itself. If the glottis of an animal be touched, there is an immediate contraction. If the heart be touched, the same phenomenon is observed. What is the difference between the excited movements of these two organs? If the brain be removed, the same events still take place. If the medulla oblongata be removed, the contractions of the stimulated larynx suddenly cease, whilst those of the heart continue as before. The difference consists, then, in the presence of the medulla oblongata, which is essential to the contractions of the larynx, but of which those of the heart are entirely independent. The influence of the stimulus upon the heart is immediate. That of a stimulus applied to the larynx must pass to the medulla oblongata, and be reflected upon the part moved.

It is interesting to compare the excited movements of the glottis and the submaxillary textures, of the sphincter ani and the tail, and of the heart, in these several parts of the recently killed turtle, placed together upon the same table. All continue vigorous for a considerable time, until the medulla oblongata or the medulla spinalis be withdrawn, when the movements of that portion of the respiratory apparatus which is attached to the head, or of the sphincter and tail, cease in an instant.

The reflex function of the medulla is most permanent and apparent to observation in those animals in which the respiration is lowest. The cold-blooded animals, the hybernating animal, and the very young of the warm-blooded, are therefore the subjects in which this function can be best studied. It may be retained, or restored, however, in the adult warm-blooded animal, by retaining the respiration, or by renewing the respiration artificially,—a fact, which constitutes another characteristic of the reflex function, and distinguishes it from irritability, and which is, in my opinion, one of the most remarkable in physiology, and highly worthy of further investigation. These remarks will readily suggest the proper choice of animals, and mode of experiment, for the display of the reflex function. I now proceed to the detail of the various experiments which I have made upon this subject, and shall then deduce the conclusions which appear to flow from them.

II. *Experiments.*

The phenomena of the reflex function, like those of the irritability, are, as I have just stated, more observable in the lower orders of animals, in the very young of the higher orders, and in the state of hybernation. It will be found, however, that the full-grown mammalia are not less distinctly endued with this property of the nervous system, whilst the functions of respiration and circulation are continued.

The first experiment which I made was upon the turtle.

This animal was decapitated in the manner usual with cooks, by means of a knife, which divided the second or third vertebra.

The head being placed upon the table for observation, it was first remarked that the mouth opened and shut, and that the submaxillary integuments descended and ascended, alternately, from time to time, replacing the acts of respiration. I now touched the eye or eyelid with a probe. It was immediately closed: the other eye closed simultaneously. I then touched the nostril with the probe. The mouth was immediately opened widely, and the submaxillary membranes descended. This effect was especially induced on touching the nasal fringes situated just within the anterior part of the maxilla. I passed the probe up the trachea and touched the larynx. This was immediately followed by a forcible convulsive contraction of the muscles annexed to it. Having made and repeated these observations, I gently withdrew the medulla and brain. All the phenomena ceased from that moment. The eye, the nostril, the larynx were stimulated, but no movement followed.

The next observations were made upon the other parts of the animal. The limbs, the tail, were stimulated by a pointed instrument or a lighted taper. They were immediately moved with rapidity. The sphincter was perfectly circular and closed; it was contracted still more forcibly on the application of a stimulus. The limbs and the tail possessed a certain degree of firmness or tone, recoiled on being drawn from their position, and moved with energy on the application of the stimulus. On withdrawing the spinal marrow gently out of its canal, all these phenomena ceased. The limbs were no longer obedient to stimuli, and became perfectly flaccid, having lost all their resilience. The sphincter lost its circular form and its contracted state, becoming lax, flaccid, and shapeless. The tail was flaccid, and unmoved on the application of stimuli.

This experiment affords evidence of many important facts in physiology. It proves that the presence of the medulla oblongata and spinalis is necessary to the contractile function of the eyelids, the sub-maxillary textures, the larynx, the sphincters, the limbs, the tail, on the application of stimuli to the cutaneous surfaces or mucous membranes. It proves the reflex character of this property of the medulla oblongata and spinalis, and the dependence of these motions upon the reflex function. It proves that the tone of the limbs, and the contractile property of the sphincter, depend upon the same reflex function of the medulla spinalis,—effects not hitherto suspected by physiologists.

I must now state that the phenomena which have been detailed subsist in distinct portions of the divided nervous system. If, after severing the head of the turtle, the lower extremities and the tail be separated together, in the manner usual with cooks, the phenomena which I have described are still observed in the distinct and separate portions of the animal. The head, the anterior extremities, and the tail present the movements which have been described, when severally stimulated. The posterior extremities alone were observed to be flaccid and unimpressible by stimuli; and these were found, on examination, to have been separated from their connexion with the spinal marrow.

An interesting experiment demonstrates the powerful influence of the reflex function over the sphincter and in the turtle. If, after the removal of the tail and the posterior extremities, with the rectum, and of course with a portion of the spinal marrow, water be forced into the intestine, by means of READ's syringe, both the cloaca and the bladder are fully distended before any part of the fluid escapes through the sphincter, which it then does on the use of much force only, and by jerks. The event is very different on withdrawing the spinal marrow: the sphincter being now relaxed, the water flows through it at once in an easy continuous stream, with the application of little force, and without inducing any distension, even of the cloaca.

I was first struck with the phenomena of the reflex function of the spinal marrow in the separated tail of an eel. On being excited by the point of a needle passed lightly over its surface, it contracted and moved as if it still formed a part of an entire animal.

On another occasion, having removed the head of a frog, I divided the spine between the third and fourth vertebræ, and separated the upper portion of the

animal from the lower. There were then the head, the anterior extremities, and the posterior extremities, with their corresponding portions of medulla, as three distinct parts of an animal. Each preserved the reflex function. On touching an eye, it was retracted, and the eyelids closed, whilst similar phenomena were observed simultaneously in the other eye. On removing the medulla, these phenomena ceased. On pinching the toe of one of the anterior extremities, the limb and the opposite limb equally moved. On removing the spinal marrow, this phenomenon also ceased. Precisely similar effects were observed in regard to the posterior extremities.

Similar phenomena are also observed in the snake. If the head be removed, and a pointed instrument or a lighted taper be brought into contact with any part of the surface, it is instantly moved. The motion consists in a flexion of the entire part, and in a concentric movement of the integuments towards the point irritated; so that the muscles situated along the spine, and certain muscles analogous to the panniculus carnosus, are excited to contraction. The extremity of the tail is most impressible. The function which presides over these movements subsisted in every part of the animal separated from the rest, but instantly ceased on removing the spinal marrow.

On touching a point immediately within the teeth of the upper jaw, the larynx was suddenly drawn downwards and closed. These movements could also be excited by touching the nostrils. They ceased on removing the medulla oblongata.

Similar phenomena are seen also in the very young of the mammalia. A rabbit, one day old, was immediately deprived of all voluntary or respiratory motion, with the exception of gaspings, by dividing the spinal marrow near the occiput. Yet the head and the limbs moved, on stimulating the ears or the feet. These movements ceased in a quarter of an hour, but were renewed by artificial respiration. The phenomena were precisely similar after decapitation, hæmorrhage being prevented and artificial respiration maintained. All ceased on removing the medulla oblongata and spinalis.

One of the most remarkable of the phenomena attached to the reflex function in animals, is that presented by those muscles of the hedgehog (*Erinaceus europæus*) by means of which that animal assumes, in certain circumstances, the form and firmness of a ball. The reflex function seems especially to con-

nect the roots of the spines with the muscles. If the animal be examined under the influence of hybernation, the reflex function continues for some hours after the brain is removed; the panniculus carnosus, the limbs, the tail, the larynx, the sphincter ani, remain excitable, and retain a degree of tone. These phenomena cease on removing the medulla spinalis.

The phenomena of the reflex function seen in the panniculus carnosus, and in other muscles of the hedgehog, are also particularly displayed in the very young animal, in which the peculiar movements of this creature are excitable for a considerable time after decapitation, or the division of the spinal marrow, and long after the cessation of the voluntary and respiratory motions, when it is in a languid and dying state.

In the case of the decapitated young hedgehog, after all gasping has ceased, motions of the larynx are still excited on irritating the nostrils, or on irritating the medulla itself; just as the peculiar motions of the trunk are excited on irritating the limbs, tail, or spines,—or the spinal marrow.

Nor are we without evidence that the same principles obtain in the human subject. The condition of the infant born without cerebrum or cerebellum, and breathing from the influence of the medulla oblongata alone, is precisely that of the reflex function, with the addition of respiration. Such a case has been witnessed and described by Mr. LAWRENCE *. “The child moved briskly at first, but remained quiet afterwards, except when the tumour was pressed, which occasioned general convulsions. It breathed naturally, and was not observed to be deficient in warmth, until its powers declined. I regret that, from a fear of alarming the mother, no attempt was made to see whether it would take the breast: a little food was given it by the hand. It voided urine twice in the first day, and once a day afterwards: it had three dark-coloured evacuations. The medulla spinalis was continued for about an inch above the foramen magnum, swelling out into a small bulb, which formed the soft tumour on the basis of the skull. All the nerves, from the fifth to the ninth, were connected to this.” This brief detail is full of interest. The respiration was natural, the medulla oblongata being entire. Swallowing was effected when food was brought into contact with the pharynx; the sphincters performed their functions; the limbs were moved when the skin was first impressed by the

* Medico-Chirurgical Transactions, vol. v. page 166.

atmospheric air. There was no indication of sensation—the child remained quiet after the first brisk movements; and no event is mentioned which could establish the existence of voluntary motion,—the acts of swallowing, and of the expulsion of the urine and fæces, with the functions of the larynx and of the sphincters, belonging distinctly to the reflex function.

M. LALLEMAND has briefly described a case of anencephalous foetus*. “J’ai vu, il y a quatre ans, à l’Hôtel-Dieu, un fœtus anencéphale, à terme, ou à peu près, qui vécut trois jours. Pendant tout ce temps il poussa des cris assez forts, exerça des mouvemens de succion toutes les fois qu’il sentit quelque chose entre ses lèvres; mais on fut obligé de le nourrir avec du lait et de l’eau sucrée, parce qu’aucune nourrice ne voulait lui donner le sein. Il exécutait des mouvemens assez étendus des membres thoraciques et abdominaux. Quand on plaçait un corps étranger dans ses mains, il fléchissait les doigts comme pour le saisir; mais en général tous ses mouvemens avaient moins d’énergie que ceux d’un fœtus de même âge.

“Le cerveau et le cervelet manquaient entièrement: il ne restait à la base du crâne que la moëlle allongée et la protubérance annulaire, avec l’origine des nerfs pneumo-gastrique, trifacial et optique. Le tout était recouvert par les débris des os du crâne, des méninges et de la peau.”

A similar case is detailed by M. OLLIVIER†, who remarks—“J’observai l’enfant anencéphale deux heures après sa naissance. Les yeux étaient constamment fermés; il poussait des cris fréquens qu’on calmait facilement en introduisant le petit doigt dans sa bouche: il exerçait alors des mouvemens de succion répétés; il agitait ses membres avec assez de force, et serrait entre ses doigts les corps qu’on plaçait dans ses mains.

“Je le revis au bout de trois heures. Les pieds et les mains étaient devenus violets et froids; la respiration ne s’opérait plus à des intervalles aussi rapprochés; les mouvemens de la moëlle épinière, que j’avais remarqués d’abord, continuaient toujours d’avoir lieu, et suivaient chacune des grandes et longues inspirations qu’il faisait. Les cris étaient moins forts et moins fréquens: on lui donna à diverses reprises de petites cuillerées de vin vieux sucré.

“Insensiblement le refroidissement des extrémités gagna le reste des mem-

* Observations Pathologiques, p. 86.

† Traité de la Moëlle Épinière, ed. 2, Paris 1827, p. 155.

bres et le tronc; la respiration s'opérait à de plus longs intervalles : elle devint convulsive. Cet état persista pendant six ou huit heures; ses cris devinrent plus faibles et plus éloignés, de même que les mouvemens de la respiration, qui étaient accompagnée de convulsions générales, et il mourut dans un véritable état d'asphyxie, après avoir poussé un cri analogue à celui qui résulte du hoquet."

M. OLLIVIER adds, (p. 161)—" Il n'existait pas ici un seul rudiment de l'encéphale et des prolongemens de la moëlle allongée; la moëlle épinière seule était restée intacte, et cependant cet enfant exerçait des suctions répétées, et serrait avec assez de force entre ses doigts les corps qu'on plaçait dans sa main; ces mouvemens étaient loin d'être automatiques comme ceux qui agitaient les membres inférieurs."

These cases, in connexion with the preceding one, are full of interest. The peculiar cries, which resemble, in their rationale, the croup-like convulsion from dentition; the closed state of the eyelids; the action of suction excited by the contact of the finger; the closure of the fingers excited by objects placed in the palm of the hand, and the movements of the inferior extremities, in this acephalous infant, are phenomena of the reflex function of the most deeply interesting character.

The following facts are extracted from a letter addressed by Mr. SWEATMAN to Sir CHARLES BELL, and published in the "Nervous System"*:—"After the membranes had given way, and the liquor amnii had escaped, the midwife on examining found another membranous bag presenting, which she naturally supposed belonged to a second child, and therefore did not interfere. During the passage of this bag under the os-pubis, it suddenly burst, and the whole of the brain escaped from the opening very much smashed, and hanging together only by its membranes. The child breathed with perfect freedom and cried strongly, rolling its eyes about in a wild, staring manner. It moved its lower extremities freely, and that not from spasm, but obviously in obedience to external impressions. There was no motion whatever of the upper extremities.

"In this state it remained for about three hours, when all motion in the extremities ceased, the eyes became fixed, and the breathing gradually slower, till it ceased altogether, just seven hours after the birth of the child. During

* Appendix, p. cxxxvi.

this time neither urine nor meconium passed, nor had there been any hæmorrhage from the vessels of the brain.

“On examination the occipital bone and the posterior part of several of the cervical vertebræ were found wanting, and their place had been occupied by fluid, surrounded by a membranous bag; an instance of spina bifida of the neck. The spinal marrow was perfect.

“A somewhat similar case occurred to me about three years ago, when I had occasion from peculiar circumstances to remove the brain of a child through the anterior fontanelle. In that instance, about ten minutes elapsed before its birth, yet it drew a deep inspiration, and would have cried had it not been prevented; and the motions of the lower extremities continued about half an hour, although the whole of the brain had been removed, and a blunt instrument repeatedly thrust down the foramen magnum *.”

It is distinctly proved, by this series of observations, that the reflex function exists in the medulla independently of the brain; in the medulla oblongata independently of the medulla spinalis; and in the spinal marrow of the anterior extremities, of the posterior extremities, and of the tail, independently of that of each other of these parts, respectively.

There is a still more interesting and satisfactory mode of performing the experiment: it is to divide the spinal marrow between the nerves of the superior and inferior extremities. We have then two modes of animal life: the first being the assemblage of the voluntary and respiratory powers with those of the reflex function and irritability; the second, the two latter powers only: the first are those which obtain in the perfect animal, the second those which animate the foetus. The phenomena are precisely what might have been anticipated. If the spinal marrow be now destroyed, the irritability alone remains, —all the other phenomena having ceased.

The spinal marrow of a frog was divided between the anterior and posterior extremities. It was immediately observed that the head and the anterior extremities alone were moved spontaneously and with design, the respiration being performed as before. But the posterior extremities were not paralyzed: they were drawn upwards, and remained perfectly motionless, indeed, unless stimulated; by the application by any stimulus, they were moved with

* See a similar case by Mr. HAMMOND, in the Medico-Chirurgical Transactions, vol. xii. p. 308.

energy, but once only, and in a manner perfectly peculiar. The stimulus was not felt by the animal, because the head and anterior extremities remained motionless at the time it was applied. Nothing could be more obvious, and indeed striking, than the difference between the phenomena of the functions of sensation and volition observed in the anterior part of the animal, and those of the reflex function in the posterior: in the former there were spontaneous movements with obvious design; in the latter, the mere effect of stimulus.

The same experiment was made upon the toad; but for some reason, probably anatomical, it does not succeed so uniformly in this animal as in the frog.

The experiment was repeated upon a guinea-pig. The effect was an immediate and total paralysis of sensation and voluntary motion in the posterior extremities: there was no expression of pain when they were pinched, nor was there the slightest indication of a power of spontaneous motion: they were dragged along when the animal moved. But they were not unimpressible by stimuli, nor destitute of the power of moving when stimulated: on the contrary, when pinched, they displayed a sort of repeated, hurried motion, altogether peculiar. The power of the sphincters was evidently preserved. In a word, the reflex function remained entire.

In all these experiments the upper part of the animal presented the phenomena of sensation and of spontaneous movements; in the lower, there was total paralysis of these powers; yet the reflex function, the excitability, the firmness of the limbs, and the irritability remained. It now remains to be stated, that the reflex function admits of *exaltation* and of *diminution*.

If a frog be made to swallow a watery solution of strychnine or of opium, or if such a solution of strychnine or opium be applied to the skin, the animal soon becomes affected with symptoms perfectly similar to those of tetanus. The surface becomes highly susceptible to the impression of stimuli, and the muscles of the limbs become affected with continued spasmodic action. The affection is obviously one of augmented reflex function of the medulla. It accordingly ceases instantly on destroying the nervous masses.

A frog made tetanic by opium was decapitated, and divided just below the third vertebra. The eyes were retracted, and no movement could be detected on irritating the eyelids or skin. Both the anterior and posterior extremities remained susceptible, and tetanic, as before: the limbs were moved in the same

spasmodic manner by the same slight impressions. All was changed on removing the brain and spinal marrow. The eyes were no longer retracted. The muscles of the limbs were immoveable under the action of stimuli, and perfectly flaccid, having lost their exalted tone.

Precisely similar phenomena were observed when the frog was made tetanic by opium or strychnine and divided into three portions, the head, the anterior and the posterior extremities ; and in the eft made tetanic and divided into the head, anterior and posterior extremities, and tail. Each part remained tetanic, impressible by the slightest touch, and spasmodically contracted on any application of stimulus. The tetanus in each is instantaneously terminated by destroying the corresponding portion of spinal marrow, the head, the limb, or the tail, instantly manifesting a perfectly relaxed and flaccid condition of the muscles. The irritability remains unimpaired.

These facts complete the proof that the phenomena which I have referred to the reflex function, do not depend either upon sensation and volition, or upon irritability. It is plain that the spasmodic actions in tetanus are not voluntary actions, and they obey the same laws as the movements observed in an animal, or parts of an animal, not tetanic, under the influence of stimuli. It is equally plain that phenomena which depended upon excited irritability would not cease whilst that irritability remained unimpaired*.

The phenomena of tetanus, in its effects upon the limbs, enable us to conceive more distinctly than we should otherwise do, the effect of the reflex function in its natural state, in maintaining the due degree of balance and antagonism of the muscles and firmness of the limbs.

If a few drops of dilute hydrocyanic acid be placed upon the tongue of a frog, a state of things the reverse of that just described as the effect of opium or strychnine is induced: the contractions which depend on the reflex function are observed to become less and less energetic and excitable, and at length cease altogether.

* Having observed these facts in connexion with the reflex function, it became a question whether the rigidity of the muscles immediately consequent to death depends upon the same principle. Two rabbits were killed; in one the spinal marrow was destroyed, in the other it was left entire. Both, however, became equally rigid. So that the spasm of death is a mere effect of irritability, and not of the reflex function of the spinal marrow.

Having thus detailed the phenomena of the reflex function, as they are observed in their ordinary and augmented and diminished degrees of force, I shall briefly enumerate some of those *excited* motions observed in various parts of the animal frame, which are obviously referrible to the same function.

The most healthy condition of the reflex function is that, the result of which is the due state of balance between antagonist muscles. But certain excited states of this function can scarcely be viewed as otherwise than healthy: such are—winking when an object touches the eyelid, the singular effect of dashing cold water on the face, and the singular effect of tickling* upon the respiration, sneezing from irritation of the nostrils, cough from that of the larynx, vomiting from that of the pharynx, strangury from irritation of the rectum, and tenesmus from that of the bladder, &c.

The excited reflex function is observed on touching the eye, the nasal fringes, or the larynx, in the separated head of the turtle; and on touching the sphincter, the tail, or the limbs, of the separated lower portion of that animal; in the frog, the lower extremities are sometimes moved with violence even, on the application of a stimulus, after the division of the spinal marrow. All the systems of muscles, therefore, obviously partake of this remarkable action.

It is plain, from the preceding observations, that the reflex function may be viewed as subsisting in its natural state, in its state of general excess or failure, and in its state of momentary and partial excitement.

III. Pathology.

There still remains an interesting part of this inquiry. What relation does the reflex function bear to the art of physic? It will soon be seen that it throws a ray of light over some obscure points in medicine. Indeed the study of the reflex function appears to me to reveal and explain a totally new order of facts in pathology, and to lead to a new division of the diseases of the nervous system, coinciding with the different modes of operation of their causes, into those of *centric* and those of *eccentric* origin.

One of the most interesting of medical subjects, in relation to the reflex

* I can readily imagine that tickling may have been carried to such an extent as to interrupt the respiration and prove fatal by asphyxia, as in a recent instance said to have occurred on the Continent.

function, is that of dentition. Dentition is a sort of natural experiment upon this function. The general convulsion, the strabismus, the spasm of the fingers and toes, the croup-like affection of the respiration, the repeated vomitings, the tenesmus, the strangury, the involuntary discharge of urine and of the fæces, from its operation, denote the influence of irritation of the maxillary nerves, through the medium of the medulla, upon the muscles of voluntary and respiratory motion, of the eye, the larynx, the sphincters, &c.; in the human subject, and indicate so many arcs of the reflex function. However these *facts* may have been known, their true *rationale* has not been discovered. In all such cases the remedy is, to relieve the part in which the cause is operating. In the present instance the maxillary nerves and vessels are to be relieved by free scarification; the lancet should be used freely, daily, or still more frequently.

The young of other animals, and especially of the feline and canine species, are exceedingly subject to similar effects from dentition, which are not unfrequently fatal. The fatal event is frequently owing to interrupted respiration. In one instance, the asphyxia was averted, in a very young puppy, by artificial respiration, effected by alternate compression and relaxation of the parietes of the thorax.

The reflex function is far more excitable in the very young animal. The second dentition rarely, therefore, induces such affections as the first.

With the effects of dentition in infants, some affections of the adult may be compared, as chorea, some forms of epilepsy, and some forms of asthma. The diseases to which these designations have been given vary exceedingly in different instances; inasmuch as some cases are of centric and others of eccentric origin. One characteristic distinguishes the latter form of the disease,—it usually combines more affections of the reflex function than one. Such a form of epilepsy, for example, combines hickup, or even vomiting, with the epileptic attack. The usual source of those forms of disease is in the intestinal canal, the stomach being irritated by improper diet or the bowels by morbid contents. This division of the subject leads to an important distinction of these cases into those which admit comparatively more easily, and more difficultly, of cure.

Epilepsy is plainly of two kinds: the first has a centric origin in the medulla itself; the second is an affection of the reflex function, the exciting cause being eccentric, and acting chiefly upon the nerves of the stomach or intes-

tines, which consequently form the first part of the reflex arc. The fact of the frequent occurrence of a fit of epilepsy in coitu is very interesting in reference to the reflex function: it distinctly connects these two events; and it affords another instance of an influence exerted, through the medium of this function, between distant parts of the spinal marrow. There is but a step, as it were, from the normal affection of the nervous, muscular, and respiratory systems, in that circumstance, to an attack of epilepsy itself.

The disease termed asthma claims rather more than an incidental notice in this place. True asthma, viz. that form of this disease which occurs in youth, and assumes a distinctly spasmodic form and course, like so many other morbid conditions of the reflex function, frequently arises from gastric or intestinal irritation. It is also frequently excited by the contact of certain powders, as that of ipecacuanha, with the larynx, just as sneezing is induced by similar impressions upon the nostrils. It appears to consist in an action excited, through the reflex function, in the larger bronchia. The influence of the smoke of the stramonium in relieving the attack of asthma is another argument in favour of its being an affection of the reflex function. Indeed, a comparison of the various causes, the mode of attack, the course, and the effects of remedies, in this singular morbid affection, alike denote its relation to this peculiar function.

With the effects of dentition, those of gastric or enteric irritation, in their multiplied forms, may be compared.

Tenesmus and strangury are affections of other arcs of the reflex function.

One circumstance in the pathology of the reflex function is very remarkable. Several forms of the morbid affections of this function occur during the first sleep. This is the case with the croup-like affection arising from dentition, with spasmodic asthma, and with a peculiar painful affection of the rectum, not hitherto described.

Tetanus and hydrophobia appear equally to result from injuries inflicted upon the extremities of certain nerves, by means of which the morbid influence is conveyed to the medulla, whence it is reflected through the motor nerves to the muscular system. As free lancing of the gums in dentition, so the early division of the wounded nerve or amputation in tetanus, has, at once, checked the morbid affection. Is it possible that hydrophobia might be arrested by a

similar procedure? The subject is of intense interest, and deserving of the fullest attention.

Certain poisons, as the strychnine, induce excess in the reflex function; other poisons, as the hydrocyanic acid, destroy it altogether. In both cases the muscular irritability remains perfect and undiminished. It is probably through the medium of the same functions that many other poisons act upon the animal economy.

In a frog, recently killed by strychnine, the irritability of the muscular fibre remained unimpaired,—a proof that the tetanus of strychnine is an exalted condition of the reflex function, and that the consequence is the exhaustion of that function, and not of the irritability. Another frog, destroyed by the hydrocyanic acid, presented similar phenomena of unimpaired irritability on the application of galvanism. In either case, if the animal be placed in water through which a slight galvanic spark is passed, the limbs are immediately and forcibly extended.

The study of the reflex function will doubtless throw an important light upon toxicology, as well as some parts of pathology, and of the causes and treatment of diseases,—subjects which, as they are more immediately connected with medicine, I purpose forthwith to pursue elsewhere.

Diseases of the nervous system, then, may be divided into those which have their origin at the nervous centres, and those which originate at a distance from those centres; and especially in some part of the nervous arc, the function of which has formed the subject of this paper,—into those of *centric* and into those of *eccentric* origin. It is highly probable that the diseases of the latter class are more numerous than they may at first be supposed to be. Chorea, hysteria, tremor, and convulsion have, doubtless, sometimes a centric, sometimes an eccentric origin. In the latter case, the nervous centres may become morbidly affected in the course of the disease, and the appearances after death may mislead the medical inquirer as to the original cause and seat of the disease. But the whole of this investigation must be reserved for the Transactions of another Society. I shall add but one fact more of a medical character in this place.

LEGALLOIS appears to have experienced great difficulty in explaining the occurrence of paralysis from disease of the cerebrum, impressed, as he was

that the spinal marrow constituted the source of voluntary motion. He observes, "Quand bien même on n'apercevrait aucun moyen de les concilier, il n'en demeurerait pas moins vrai, d'une part, qu'une affection bornée uniquement au cerveau peut ôter le sentiment et le mouvement volontaire à la moitié du corps, et de l'autre, que le sentiment et le mouvement volontaire peuvent subsister et être entretenus dans un animal décapité. Quelque opposés que ces faits paraissent être, il faut se souvenir que deux faits bien constatés ne peuvent jamais s'exclure l'un l'autre, et que la contradiction qu'on croit y remarquer tient à ce qu'il y a entre eux quelque intermédiaire, quelque point de contact qui nous échappe *." The facts which have been detailed in this paper enable us readily to remove this difficulty, and to account for the paralysis induced by disease of the cerebrum, on one hand, and for the movements of an anencephalous foetus in utero, or of a decapitated animal, on the other. The paralysis consists in the loss of voluntary motion; the movements of the anencephalous foetus result from the agency of the reflex function of the medulla spinalis. LEGALLOIS' error was that of mistaking the phenomena of the reflex function for sensation and voluntary motion; and his difficulty naturally arose out of this error. There is no real discrepancy between the two orders of facts to which LEGALLOIS refers.

The same facts enable us to understand how a perfect action of the sphincters is compatible with paralysis of the limbs from disease of the cerebrum, and even of the higher parts of the medulla spinalis; whilst paralysis of the sphincters is usually conjoined with paralysis of the limbs, arising from disease of the lower part of the spinal marrow. The first intercepts the principle of voluntary motion; the second affects the very seat of the reflex function which presides over the action of the sphincters.

IV. *Inferences.*

I shall now briefly enumerate the inferences which flow from the preceding facts and experiments.

Physiologists have hitherto enumerated only *three* sources or principles of muscular action,—volition, the motive influence of respiration, and irritability.

There is, however, a *fourth* source of muscular motion distinct from any of

* Op. cit. p. 21.

these, though not hitherto distinguished, to which I have ventured to give the designation of *the reflex*.

Volition and the motive influence of respiration are direct in their course, and spontaneous in their action; the former proceeding from the cerebrum, the latter from the medulla oblongata*.

The movements of irritability are the result of the immediate application of a stimulus to the nervo-muscular fibre itself.

The reflex function is different from any of these :

It remains attached to the medulla spinalis, when the cerebrum and the medulla oblongata are removed: it is not direct like volition, or the motive power of respiration.

Its seat is the medulla generally: it ceases when the medulla is removed, leaving the irritability entire: it is not excited immediately, like the movements of irritability, but mediately, in a reflex course, through the medulla, from the part stimulated to the part moved.

In a state of health, the reflex function presides over the orifices and terminations of the internal canals, such as the glottis and the sphincters, preserving the former open, the latter closed; and it maintains the due tone of each muscle, and the due equilibrium of each system of muscles.

When excited, it gives origin to the movements observed in deglutition, or vomiting, sneezing, tenesmus, &c. The fingers passed into the pharynx of a dog, through an incision made between the thyroid cartilage and the os

* M. FLOURENS seems clearly to have determined that sensation and volition are seated in the cerebrum. LEGALLOIS (*Œuvres*, p. 17,) and he have ascertained that one office of the cerebellum is to regulate the voluntary motions. LEGALLOIS and Sir CHARLES BELL have shown that the medulla oblongata^a is the source of the respiratory motions. It is now, for the first time, I believe, shown that a peculiar function of the medulla, superadded to its functions as a mere nervous chord, is that of imparting a state of equilibrium to the muscular system, independently of the influence of the organs which originate and regulate the voluntary and respiratory motions. These several functions are separated, and, in a certain degree, isolated, by removing the cerebrum, the cerebellum, and the medulla oblongata in succession; the last stage of the experiment leaves the reflex function alone,—a function which supplies the deficiency left by the investigations of LEGALLOIS, M. FLOURENS, and Sir CHARLES BELL, and constitutes the complement of the functions of the nervous system.

^a This discovery of LEGALLOIS is amongst the most brilliant in physiology, and obviously presents the nucleus of that, still more splendid, of the system of the respiratory nerves by Sir CHARLES BELL. *Œuvres*, pp. 63, &c. *The Nervous System*, pp. 222, cxxv. &c.

hyoides, excites the act of deglutition*; passed over the root of the tongue or the fauces, it excites the associated actions of the muscles of the larynx and of expiration†, which constitute the act of vomiting.

When morbidly augmented, it constitutes certain forms of disease, as tetanus, hydrophobia, certain forms of tremor, paralysis agitans, chorea, stammering, &c.; when diminished, it induces those forms of tremor observed when the vital powers are enfeebled.

When otherwise morbid, it occasions other forms of disease, as the convulsion, the croup-like respiration, the affection of the sphincters, observed in dentition, the various effects of intestinal irritation, &c.

The effects of the excited reflex function are sometimes observed in a part *near* that irritated, as in the eyelids in winking, in the glottis on inhaling a drop of water or particle of food, in the sphincter ani in dysentery, &c.; sometimes in parts *remote*, as in the irritation of teething when this induces strabismus, convulsion, the croup-like respiration, relaxed sphincters, &c.

However some of the facts detailed in this paper may have been previously known,—and many were so known‡,—they have never been accurately distinguished from sensation and volition, and associated with a peculiar reflex function of the medulla oblongata and medulla spinalis, influencing other organs besides the limbs, and constituting the principle of tone and of a particular series of actions. It has long been known, for example, that the limbs of a decapitated animal moved on being stimulated; but the phenomenon was confounded with sensation and voluntary motion. It has long been known that carbonic acid could not be inhaled through the larynx; but it has not been shown that this phenomenon depends upon the presiding agency of the medulla oblongata; nor has it been distinctly demonstrated that the functions of the sphincter ani, by which the intestinal excretions are retained for a time, is constantly dependent upon a similar agency of the lower part of the medulla spinalis. In like manner, the facts relative to the irritability were altogether known before GLISSON and HALLER finally separated this principle of motion

* De l'Usage de l'Épiglotte, p. 3.

† See a Memoir by the author on the Mechanism of the Act of Vomiting, in the Journal of the Royal Institution, 1828, Part I., (April to June,) p. 388.

‡ Compare WHYTT, LEGALLOIS, MAYO, &c.

from sensation and volition, with which, like the reflex function, it had previously been confounded.

An interesting parallel might, indeed, be instituted between the principle of the reflex function and that of the irritability, in regard to their history and degree of importance: their history is the same; for both had been confounded with sensation and voluntary motion*: their importance is precisely the same; for each presides over its own distinct order of functions.

LEGALLOIS plainly mistook the reflex function of the medulla for the principle of sensation and voluntary motion; and no physiologist has distinguished its agency, in the function of the larynx and of the sphincters, from the influence of the brain, or from irritability. The view of M. CRUVEILHIER, that the medulla spinalis is a mere nervous chord, is at variance with all the facts and experiments detailed in the course of this paper.

It is obviously from the mistake which has been pointed out, that LEGALLOIS experienced the difficulty expressed in the following words: "Comment se fait-il qu'après la décapitation, les seuls mouvemens inspiratoires soient anéantis et que les autres subsistent? C'est là, à mon sens, un des grands mystères des puissances nerveuses, mystère qui sera dévoilé tôt ou tard, et dont la découverte jettera la plus vive lumière sur le mécanisme des fonctions de cette merveilleuse puissance†." It was impossible to explain this difficulty whilst the movements of the excited reflex function were confounded with those of voluntary motion; but when this distinction is duly made, nothing is more easy. Decapitation removes, in fact, the sources both of voluntary and of respiratory motion; both these kinds of motion consequently cease: but a class of motions still remains, viz. those of the reflex function, attached to the remaining portion of medulla. Thus is the veil raised from this apparent 'mystery'.

As LEGALLOIS has confounded the reflex function with the sensibility and voluntary motions, M. BRACHET‡ has confounded it with the functions of the ganglionic system, or the sympathetic. The latter physiologist concludes, that whatever function remains after the division of the spinal marrow, in the organs below that division, must be referrible to the influence of the ganglionic system. In this manner he attempts to prove that some parts of the act and function

* Compare WHYTT and LEGALLOIS.

† Œuvres, pp. 63, 64.

‡ Du Système Nerveux Ganglionnaire, p. 246, &c.

of generation, in both sexes, besides the secretions, depend upon this influence ; whereas it is certain that they depend upon the lower portion of the medulla spinalis and belong to the reflex function. It is obvious, that, whilst the secretions may depend on the ganglionic system, the act of excretion, and especially the action of the ejaculatory muscles, is an excited act of the reflex function, which has been fully proved to subsist in every portion of the divided medulla spinalis. This view of the subject is greatly confirmed by a comparison of the act alluded to, with that of deglutition (p. 640, note), and others demonstrably belonging to the reflex function. We know that some reptiles remain in coitu after the head is removed. This is then an act of the reflex function alone. It may take place without sensation, as in cases of disease of the medulla spinalis.

I may state, in conclusion, that all the functions of the muscular system which remain after the sources of the motive influence of the voluntary and respiratory motions are removed, with the exception of those of the heart, and other muscles which contract upon the principle of excited irritability, depend upon the reflex function.

The principles of the movements in the animal economy, viewed in an anatomical and functional point of light, may now be enumerated thus :

1. The cerebrum, or the source of the voluntary motions.
2. The medulla oblongata, or the source of the respiratory motions.
3. The medulla spinalis generally, the middle arc of the reflex function.
4. The nervo-muscular fibre, or the seat of the irritability.
5. The sympathetic, or the source of nutrition, of the secretions, &c.

It is not pretended that this arrangement is either strictly accurate or complete. These principles of action are, besides, frequently and variously combined, and much ulterior investigation is required to ascertain the share and fix the limit of each in various compound operations of the animal economy.

The reflex function of the different portions of the medulla presides over their corresponding organs : the medulla oblongata presides over the larynx and the pharynx ; the lumbar and sacral portion of the medulla spinalis presides over the sphincter ani, the cervix vesicæ ; and the intervening portions of the medulla give tone and equilibrium to the corresponding portions of the muscular system, and what LEGALLOIS has so vaguely designated "*life*," to the corresponding regions of the body. But the operation of the reflex function is by

no means confined to parts corresponding to distinct portions of the medulla. The irritation of a given part may, on the contrary, induce contraction in a part very remote: the irritation of teething may induce spasmodic action or relaxation of the sphincters: the irritation of the nostrils, in the case of a young hedgehog, when so languid that voluntary motion and respiration had ceased, induced as energetic contraction of the most distant part of the panniculus carnosus and of the muscles of the posterior extremities, as irritation of the posterior extremities or tail themselves.

It would seem, from what I have observed in the young of the hedgehog and of other animals, when languid, torpid, or *dying*, that the voluntary motions cease first, then the respiratory motions, next those of the excited reflex function, and, lastly, those of the irritability; the last act of the irritability being that which induces the cadaveric rigidity. After all evidence of irritability has ceased, it is probable that the functions of the sympathetic may still continue.

Such is the order, then, in which this series of functions disappear in death; an order which is inverted when the same functions and their appropriate organs gradually came into existence, in the foetal and natal states, and in the progressive series of the animal kingdom. The movements of the foetus in utero, are entirely phenomena of the reflex function: they occur in the anencephalous as well as in the perfect foetus*. This function and the irritability constitute, indeed, the principles of life and motion in the *foetal state*.

The functions, in *sleep*, seem to be diminished, and that in the same order. This is particularly seen in the deep lethargy of the hedgehog. The animal becomes quiescent; then it nearly ceases to respire; then the action of the panniculus carnosus yields to partial relaxation; lastly, the heart beats with a reptile slowness. In ordinary sleep, the muscles which retain the eye open lose their powers, and the eyelids close by an act of the reflex function, just as they are kept closed in the anencephalous infant. The eye is only partially closed, even during sleep, in cases of extreme languor and exhaustion, with diminished energy of the reflex function. Volition is first impaired, and the eyelids close; the reflex function next fails, and the eyelids close partially only.

It appears probable that the facts of this paper may lead to some important additions to our knowledge of anatomy, by inducing an accurate inquiry into

* See M. LALLEMAND'S *Observations Pathologiques*, p. 68.

the origin, course, connexion, and distribution of the subcutaneous, or sub-mucous, and muscular nerves, which constitute the arcs of the reflex function. There can be no doubt that a system of nerves takes its origin from the lower portion of the spinal marrow, to supply the sphincters and the organs of generation, which may be compared to those which centre in the medulla oblongata. The medulla is also, in its whole course, the source of nerves which supply the limbs, the tail, and the panniculus carnosus, in those animals which possess these structures respectively.

It was observed in one frog that the strychnine applied to a single posterior extremity induced general tetanus. General tetanus, in the human subject, is the effect of the local wound of a nerve. These facts demonstrate the strict connexion and unity of the different parts of the nervous system.

The anatomy of the reflex function must be particularly studied in the medulla oblongata; in the portions of the spinal marrow which give origin to the nerves of the anterior and posterior extremities; in that of the intermediate space which supplies the trunk; in that which is the source of the nerves of the sphincters, the ejaculators, &c., and in that which supplies the tail; and, lastly, in reference to the several columns of which the spinal marrow is composed. I think the investigation of the anatomy will, for various reasons, be best pursued in the hedgehog.

It is gratifying to me to state that no part of these experiments has inflicted pain, beyond that of prompt decapitation, or division of the spinal marrow. This is true, at least, if the conclusion be correct, that when the head is removed from the body, sensation and volition cease, whilst the reflex function and the irritability alone continue; and it may be satisfactory to the humane to know that the motions of the eel, for example, after the head is removed, are not motions arising from sensibility, but from another principle, as distinct from feeling as the irritability of the mere nervo-muscular fibre. This fact will suggest the propriety, as well as the means of avoiding such monstrous cruelty as that of skinning eels alive. This will be effectually done by first removing the head, however the animal may afterwards move on the application of stimuli, and *appear to feel*.

V. *Recapitulation.*

To avoid misapprehension, I think it right, in conclusion, very briefly to recapitulate the claims of this paper :

1. Many of the facts which depend upon the reflex function have long been known to physiologists :

2. But these facts only extend to the excited action of the reflex function, seen in the limbs, and even they have been erroneously ascribed to sensation and volition, or instinct :

3. The facts of excited movements of the larynx, pharynx, sphincters, and ejaculators, and of the panniculus carnosus, have not been shown to be allied to these, and to be dependent on the same individual function of the nervous system :

4. It has not been shown that this function, in its natural state, constitutes the principle of equilibrium and tone, in the whole muscular system, and the principle which presides over the orifices and sphincters of the internal canals:

5. And certainly not, that this principle, morbidly affected, constitutes, in its different forms, the diseases arising from dentition, and the diseases termed tetanus, hydrophobia, chorea, paralysis agitans, certain forms of epilepsy, of tremor, of asthma, &c. &c. :

6. Nor that the same individual function is augmented or diminished to a fatal degree, by certain poisons.

7. This series of facts has not been duly associated and shown to belong to *one particular order* :

8. The principle of action in this order of facts has not been demonstrated to be at once excited, and reflex, in its operations, to be essentially connected with corresponding portions of the medulla oblongata and medulla spinalis, and to be independent of the brain :

9. Nor has it been clearly distinguished from the other sources and principles of muscular motion existing in the animal economy, viz. volition, the motive influence of respiration, and irritability, or shown to constitute, with the irritability, the principle of life in the foetal state :

10. The reflex function appears, in a word, to be the *complement* of the functions of the nervous system hitherto known.

I trust it will be found, from this brief recapitulation, that the foregoing paper may have done some little service to physiological science. I consider the subject as but sketched,—the investigation as but just begun. One part of this inquiry is altogether untouched,—the influence of the mind and emotions, and the corresponding parts of the nervous system, upon the organs which are the subjects of the reflex function. The muscles of voluntary and respiratory motion are alike under the influence of the reflex function; and the muscles over which this function more peculiarly presides are impressible through volition and respiration: other muscles, which are especially attached to the reflex function of the lower portion of the medulla spinalis (p. 661), are apparently under the influence of the cerebellum*. Mental emotions modify the reflex function: they induce sickness, relax the sphincters: they also aggravate the diseases of this function, inducing the attacks of epilepsy, of the croup-like convulsion, &c.

* See SERRES, *Anatomie Comparée du Cerveau*, tome ii. p. 601, &c.

XXVII. *On the present Situation of the Magnetic Lines of equal variation, and their Changes on the Terrestrial Surface.* By PETER BARLOW, Esq., F.R.S., Cor. Memb. Inst. France, and of the Imp. and Royal Academies of Petersburg, Brussels, &c.

Received May 6,—Read May 9, 1833.

THE great progress which has been made within a few years in establishing the laws of magnetic action, as subsisting between magnets on each other, and of these on iron, leads to a rational expectation that the still unknown and mysterious laws of terrestrial variation may by perseverance be likewise elicited.

This hope has induced me to undertake the task of collating and arranging all the valuable information recorded in several recent and important voyages and journeys of discovery, surveys, &c., undertaken by the British and by some foreign Governments. In all these cases the officers selected to conduct them have been of the highest scientific character: the subject of magnetism has been, during the time of their performance, the favourite pursuit of many highly talented philosophers in all parts of Europe. Instruments of the most perfect description have been employed, and more than ordinary care bestowed upon the magnetic observations.

Many of these have been made in regions, of all others, the most interesting in such an inquiry, namely, in the vicinity of a principal focus of magnetic energy; others are equally important from their extensive range. In the voyage under the command of Captain BEECHER, more than 75,000 miles of the earth's surface were traversed, and, throughout, the errors from local attraction were carefully excluded. The surveys of the coast of Africa, America, and New Holland, by Captains OWEN and KING, and many others which might be enumerated, performed by officers in the British navy, and the circumnavigation of the southern pole by Captain BISCOE, have alone furnished an immense stock

of valuable information; but to these we have to add the voyages by Captain LUTKE in the Russian service, of Captain DUPERRÉY in the French service, and the valuable references I have been enabled to obtain through the kindness of Captains BEAUFORT and HORSBURGH, recorded in their respective offices. These together formed such a mass of well-authenticated observations, as seemed to render it very desirable to collect and arrange them, so as at least to furnish a sure foundation for future comparison, if not for immediate investigation.

With regard to the mode of arrangement, the charts of HALLEY, YATES, HANSTEEN, &c., naturally led me to the idea of one of the same form, as given in the accompanying engravings (Plates XVII. and XVIII.); but feeling dissatisfied with the great distortion of the lines in the higher latitudes, and the necessary want of continuity on the two sides of the chart, I determined to begin *de novo*, and to lay the lines all down on a 15-inch globe, where they of course are exhibited in their natural situation, and in regular continuity, the latter condition being only attainable in the latter form; and I extremely regret that I am not able to publish the work in this form, being so much better calculated to elucidate the subject, than any chart that can be constructed. As I was desirous of keeping myself entirely free from any theoretical notions, my object being principally to fix the foundation for future views and comparisons, I have laid down such lines only as are drawn from actual observations, so that where these failed I have left the parts blank; this is chiefly observable about the south pole and over lands, except in Europe, where well observed variations have enabled me to continue them over both land and water. Having thus devoted the oceans to the variation lines, I had intended to have laid down the lines of equal dips upon the land: but after some consideration I have omitted these; they might, however, be introduced without confusing the lines of variation. On the globe I have coloured those oceans in which the variation is east, with a light green; and where it is west, with a light blue: in the same way, if the dip lines were introduced, those parts of the land and continents in which the dip is north, and where it is south, might be distinguished by a similar contrast of colour,—a plan which relieves the eye, and assists the mind in tracing the various configurations of the several lines.

On attentively examining these lines, either in the form of a chart, or on the globe, but particularly on the latter, it must, I think, be acknowledged, not-

withstanding their extraordinary curvatures, that they exhibit a character which indicates their being dependent on some law, however intricate and mysterious. If the variations were, as has been sometimes supposed, greatly influenced by parts immediately in their vicinity, we could not expect to find that regularity which is observable in so many, if not in all parts: throughout the Atlantic Ocean, for example, there is a continuity and softness of curvature, and unity of character quite inconsistent with such a supposition; still the lines there recorded are the legitimate deductions of a comparison of many hundred observations with each other.

Again, in the Indian Ocean we have a most extraordinary inflection of the curve of no variation, whereby we find, in traversing the earth's equator, that two thirds of it, or 240° , have easterly variation, while only 120° have westerly variation; and here again, in consequence of this extreme anomaly, I have taken particular pains, and have examined an immense number of observations, as recorded both by officers in the British navy, and in the East India Company's ships, with the greatest care, and there is no question whatever that the lines as laid down on the globe are an exact representation of those on the earth; but we see no such sudden interruptions of curvature as must occur if local causes were very influential. I may also remark, that the observations in these seas are by far more accordant and positive in their character than I generally found them in other parts,—a circumstance probably attributable to the very small dip in these seas, and the consequent high intensity of the horizontal needle, which rendered it by position less liable to disturbance from local attractions, and more determinate in its direction.

Another marked peculiarity in this ocean is, that for forty degrees the line of no variation runs nearly parallel to the equator, and then for another forty degrees down a meridian; and as in cases of no variation the magnetic pole, as we commonly understand the term, must be on the meridian of the place, it follows that the pole must also range through forty degrees, or be coincident with the pole of the world; either of which conditions is equally inconsistent with the notion that all these phenomena are due to the action of four or more magnetic poles.

Again, referring to the remarkable curves in the great Pacific Ocean, there is, notwithstanding their peculiar character, no appearance of uncertain and

anomalous attractions: the whole seems to form a system by itself. The lines, instead of extending towards the poles, as in most other parts, return upon themselves in similar, though not in regular figures: and here again I can see no possible position of four poles which can lead to such configuration.

These lines differ very considerably from those of former charts; but they are drawn from a careful examination of observations, not so numerous, certainly, as in some other parts, but still in all probability much exceeding those on which former charts in this ocean have been constructed.

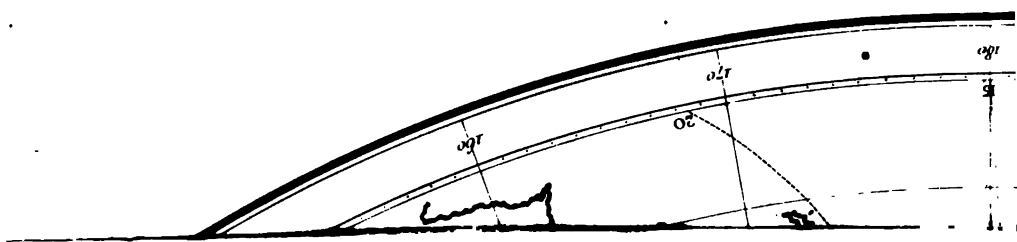
Many other peculiarities will occur to any person carefully examining the several curvatures, particularly that remarkable one found in crossing the Continent of Asia; but as I have not had an opportunity of consulting the original authorities on which these lines are founded, I shall not offer any remark upon them, except to state that they rest on the authority of a most able and indefatigable observer, Professor HANSTEN, only that a slight change was rendered necessary by the recent observations of Captain LUTKE on the coasts of Nova Zembla and the North of Europe.

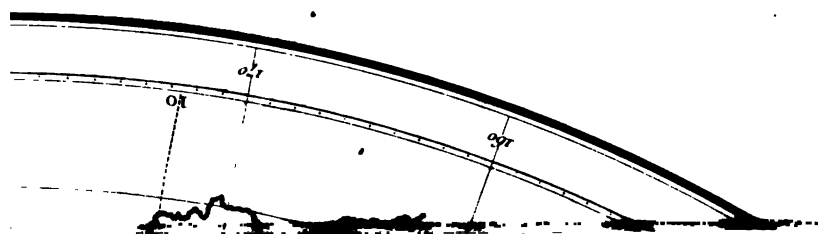
The foregoing remarks have reference to the present state of the magnetic lines; but their progressive change of situation and configuration is another important feature in terrestrial magnetism. The first notice I can find of the variation itself occurs in the year 1269, in a letter from PETRI PEREGRINI to a friend, where the author states that after several careful experiments he found it amounted to 5° east in Italy; but the method of observation at that time was very unsatisfactory: it consisted only in touching an iron needle with the loadstone, and observing its bearing before its power was lost. In 1580 the variation was certainly $11\frac{1}{4}^{\circ}$ east in London: about 1658 it was zero, the needle pointing then due north. In 1700 it was about 8 degrees west, at which time it was zero on the coast of America in the vicinity of New York, and it has remained at the latter place nearly the same ever since.

It follows, therefore, that about the year 1660, the line of no variation must have crossed the Atlantic nearly at right angles to the meridians, as it does now in the Indian Ocean.

From that time it has been gradually descending towards the south and west, and at present crosses some way inland on the eastern point of South America.

A CHART
OF
MAGNETIC CURVES
OF
EQUAL VARIATIONS





COLLATED
AND
ARRANGED

BY
PETER BARLOW F.R.S

We have not such early authority for that line of no variation which passes through Australia, but since that country has been pretty well known, at least for 60 years, very little if any change has taken place, and it seems probable the variation about this spot is as fixed as in that on the coast of America.

I refer to these two cases because they differ very considerably from all others in which a line of no variation has been known to cross; the motion for some years before and after the actual passage of that line being generally very rapid, whereas in these it is stationary or nearly so. Thus in London, the variation was $11^{\circ} 15'$ east in 1580; in 1658 the line of no variation passed our meridian, and in 1698 it was about 8° west, giving a change of 20° in a little more than 100 years; and the same is observed in all other places where the passage of the line is well determined, while in the two places referred to, it has experienced no change, or very little, in the one, for more than 130 years, and in the other probably for as long a time, but certainly for more than 60 years.

In the West Indies, the Bermudas, and a few other places, where the variation is small, the change has also been very inconsiderable; but I believe no case occurs where the variation is large and stationary,—a peculiarity which ought to be well considered in attempting a theory of these motions. Another circumstance equally remarkable is, that in all cases in which sufficient registers of variation have been made, and where the motion or change has been considerable, we may always reduce that motion to a circular rotation of a certain assumed magnetic pole about the pole of the earth: that is, we may, by assuming for each place its own pole, revolving at a given uniform rate, compute the variation of the needle at any period so as to agree very nearly with observation.

CHURCHMAN, in his Atlas, I think, was the first to make this assumption, and to compute the consequent variations in London for every ten years from 1622 to 1800; which he afterwards compared with actual observed variations, and in every case the error between the two is very inconsiderable.

In the second edition of my Essay on Magnetic Attractions, I have made a similar comparison, not by assuming the place of the pole, but by computing it from the dip and variation; and the errors or differences in this case, though certainly not so small, are still by no means considerable.

In the Article "MAGNETISM" in the Encyclopædia Metropolitana, I have

made similar computations for Paris and Copenhagen, the only two places besides London where observations are recorded for any length of time, and in both these the agreements between the computed and observed variations are still more approximate than in London.

Now it must be considered very extraordinary that such remarkable agreements as these should obtain in three places, between the computed and observed variations, through more than thirty degrees of change, or for a period of 170 years, if the hypothesis of a polar revolution were not founded in fact. Assuming then, that, from whatever cause it may proceed, such a revolution does take place, how are we to account for those stationary, or nearly stationary, points of no variation to which reference has been made?

The only reply to this question appears to be, that there is no determinate pole to which all needles point, but that every place has its own particular pole and polar revolution, governed probably by some one general but at present unknown cause. Should this be the case, and the magnetic pole of any place be nearly coincident with the terrestrial pole, the line of no variation, notwithstanding the rotation, must remain nearly stationary; but such stationary position is impossible where the variation is considerable, although the change ought to be very slow on this hypothesis while it is passing through its maximum.

I have offered these few remarks without any intention of their being considered as illustrations of a particular theory. My only object has been in this undertaking to give an exact representation, as far as it was possible, of the present state of terrestrial magnetism, and in this I have every reason to hope I have succeeded.

In the performance of this task, which has required several months of close application, I have been greatly assisted by my son, who has executed with great accuracy the whole of the graphical part, and aided in the comparison of many thousand observations; and I shall be most happy if our joint labour should furnish the requisite data for either a present or future development of those mysterious laws which govern the magnetism of the terrestrial globe,—an object as interesting in philosophy as it is important in navigation.

Woolwich,

May 1st, 1833.

November 18th, 1833.

P.S. Since this paper was read, and the globe and chart referred to in this article were drawn, Captain Ross has returned from his long and adventurous voyage. It will be seen by a reference to the polar chart, that, although I was enabled to lay down the curves of equal variation to within a few degrees of their point of concurrence, yet they are all terminated before arriving at it, for want of sufficient data. These are now supplied ; and it is very gratifying to me, as I hope it may be also to Captain Ross and to Commander JAMES Ross, to find that the very spot in which they have found the needle perpendicular,—that is, the pole itself,—is precisely that point on my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately, and conjointly as a system. By some delay in engraving the chart, I am able to add to it the exact place of the pole, as obtained from the numerous and admirably arranged observations of Commander Ross, which I have had the pleasure and satisfaction of examining, and which I hope, in the ensuing session, will be laid before the Royal Society.

XXVIII. *Experimental Researches in Electricity.—Fifth Series.* By MICHAEL FARADAY, D.C.L., F.R.S. &c., *Fullerian Prof. Chem. Royal Institution, Corr. Memb. Royal and Imp. Acad. of Sciences, Paris, Petersburg, Florence, Copenhagen, Berlin, &c. &c.*

Received June 18,—Read June 20, 1833.

§ 11. *On Electro-chemical Decomposition.* ¶ i. *New conditions of Electro-chemical Decomposition.* ¶ ii. *Influence of Water in Electro-chemical Decomposition.* ¶ iii. *Theory of Electro-chemical Decomposition.*

§ 11. *On Electro-chemical Decomposition.*

450. I HAVE in a recent series of these Researches (265.) proved (to my own satisfaction, at least,) the identity of electricities derived from different sources, and have especially dwelt upon the proofs of the sameness of those obtained by the use of the common electrical machine and of the voltaic battery.

451. The great distinction of the electricities obtained from these two sources is the very high tension to which the small quantity obtained by aid of the machine may be raised, and the enormous quantity (371. 376.) in which that of comparatively low tension, supplied by the voltaic battery, may be procured; but as their actions, whether magnetical, chemical, or of any other nature, are essentially the same (360.), it appeared evident that we might reason from the former as to the manner of action of the latter; and it was to me a probable consequence, that the use of electricity of such intensity as that afforded by the machine, would, when applied to effect and elucidate electro-chemical decomposition, show some new conditions of that action, evolve new views of the internal arrangements and changes of the substances under decomposition, and perhaps give efficient powers over matter as yet undecomposed.

452. For the purpose of rendering the bearings of the different parts of this series of researches more distinct, I shall divide it into several heads.

¶ i. *New conditions of Electro-chemical Decomposition.*

453. The tension of machine electricity causes it, however small in quantity, to pass through any length of water, solutions, or other substances classing with these as conductors, as fast as it can be produced, and therefore, in relation to quantity, as fast as it could have passed through much shorter portions of the same conducting substance. With the voltaic battery the case is very different, and the passing current of electricity supplied by it suffers serious diminution in any substance, by considerable extension of its length, but especially in such bodies as those mentioned above.

454. I endeavoured to apply this facility of transmitting the current of electricity through any length of a conductor, to an investigation of the transfer of the elements in a decomposing body, in contrary directions, towards the poles. The general form of apparatus used in these experiments has been already described (312. 316.); and also a particular experiment (319.), in which, when a piece of litmus paper and a piece of turmeric paper were combined and moistened in solution of sulphate of soda, the point of the wire from the machine (representing the positive pole) put upon the litmus paper, and the receiving point from the discharging train (292. 316.), representing the negative pole, upon the turmeric paper, a very few turns of the machine sufficed to show the evolution of acid at the former, and alkali at the latter, exactly in the manner effected by a volta-electric current.

455. The pieces of litmus and turmeric paper were now placed each upon a separate plate of glass, and connected by an insulated string four feet long, moistened in the same solution of sulphate of soda: the terminal decomposing wire points were placed upon the papers as before. On working the machine, the same evolution of acid and alkali appeared as in the former instance, and with equal readiness, notwithstanding that the places of their appearance were four feet apart from each other. Finally, a piece of string, seventy feet long, was used. It was insulated in the air by suspenders of silk, so that the electricity passed through its entire length: decomposition took place exactly as in former cases, alkali and acid appearing at the two extremities in their proper places.

456. Experiments were then made both with sulphate of soda and iodide of potassium, to ascertain if any diminution of decomposing effect was pro-

duced by such great extension of the moist conductor or body under decomposition; but whether the contact of the decomposing point connected with the discharging train was made with turmeric paper touching the prime conductor, or with other turmeric paper connected with it through the seventy feet of string, the spot of alkali for an equal number of turns of the machine had equal intensity of colour. The same results occurred at the other decomposing wire, whether the salt or the iodide were used; and it was fully proved that this great extension of the distance between the poles produced no effect whatever on the amount of decomposition, provided the same *quantity* of electricity were passed in both cases (377.).

457. The negative point of the discharging train, the turmeric paper, and the string were then removed; the positive point was left resting upon the litmus paper, and the latter touched by a piece of moistened string held in the hand. A few turns of the machine evolved acid at the positive point as freely as before.

458. The end of the moistened string, instead of being held in the hand, was suspended by glass in the air. On working the machine the electricity proceeded from the conductor through the wire point to the litmus paper, and thence away by the intervention of the string to the air, so that there was (as in the last experiment,) but one metallic pole; still acid was evolved there as freely as in any former case.

459. When any of these experiments were repeated with electricity from the negative conductor, corresponding effects were produced whether one or two decomposing wires were used. The results were always constant, being considered in relation to the *direction* of the electric current.

460. These experiments were varied so as to include the action of only one metallic pole, but that not the pole connected with the machine. Turmeric paper was moistened in solution of sulphate of soda, placed upon glass, and connected with the discharging train (292.) by a decomposing wire (312.); a piece of wet string was hung from it, the lower extremity of which was brought opposite a point connected with the positive prime conductor of the machine. The machine was then worked for a few turns, and alkali immediately appeared at the point of the discharging train which rested on the turmeric paper. Corresponding effects took place at the negative conductor of a machine.

461. These cases are abundantly sufficient to show that electro-chemical de-

composition does not depend upon the simultaneous action of two metallic poles, since a single pole might be used, decomposition ensue, and one or other of the elements liberated, pass to the pole, according as it was positive or negative. In considering the course taken by, and the final arrangement of, the other element, I had little doubt that I should find it had receded towards the other extremity, and that the air itself had acted as a pole, an expectation which was fully confirmed in the following manner.

462. A piece of turmeric paper, not more than 0·4 of an inch in length and 0·05 of an inch in width, was moistened with sulphate of soda and placed upon the edge of a glass plate opposite to, and about two inches from, a point connected with the discharging train (Plate XIX. fig. 1.); a piece of tinfoil, resting upon the same glass plate, was connected with the machine, and also with the turmeric paper, by a decomposing wire *a* (312). The machine was then worked, the positive electricity passing into the turmeric paper at the point *p*, and out at the extremity *n*. After forty or fifty turns of the machine, the extremity *n* was examined, and the two points or angles found deeply coloured by the presence of free alkali (fig. 2.).

463. A similar piece of litmus paper, dipped in solution of sulphate of soda *n*, fig. 3, was now supported upon the end of the discharging train *a*, and its extremity brought opposite a point *p*, connected with the conductor of the machine. After working the machine for a short time, acid was developed at both the corners towards the point, i. e. at both the corners receiving the electricities from the air. Every precaution was taken to prevent this acid from being formed by sparks or brushes passing through the air (322.); and these, with the accompanying general facts, are sufficient to show that the acid was really the result of electro-chemical decomposition (466.).

464. Then a long piece of turmeric paper, large at one end and pointed at the other, was moistened in the saline solution, and immediately connected with the conductor of the machine, so that its pointed extremity was opposite a point upon the discharging train. When the machine was worked, alkali was evolved at that point; and even when the discharging train was removed, and the electricity left to be diffused and carried off altogether by the air, still alkali was evolved where the electricity left the turmeric paper.

465. Arrangements were then made in which no metallic communication

with the decomposing matter was allowed, but both poles (if they might now be called by that name,) formed of air only. A piece of turmeric paper *a*, fig. 4, and a piece of litmus paper *b*, were dipped in solution of sulphate of soda, put together so as to form one moist pointed conductor, and supported on wax between two needle points, one *p* connected by a wire with the conductor of the machine, and the other, *n*, with the discharging train. The interval in each case between the points was about half an inch: the positive point *p* was opposite the litmus paper; the negative point *n* opposite the turmeric. The machine was then worked for a time, upon which evidence of decomposition quickly appeared, for the point of the litmus *b* became reddened from acid evolved there, and the point of the turmeric *a* red from a similar and simultaneous evolution of alkali.

466. Upon turning the paper conductor round, so that the litmus point should now give off the positive electricity, and the turmeric point receive it, and working the machine for a short time, both the red spots disappeared, and as on continuing the action of the machine no red spot was re-formed at the litmus extremity, it proved that in the first instance (463.) the effect was not due to the action of brushes or mere electric discharges causing the formation of nitric acid from the air (322.).

467. If the combined litmus and turmeric paper in this experiment be considered as constituting a conductor independent of the machine or the discharging train, and the final places of the elements evolved be considered in relation to this conductor, then it will be found that the acid collects at the *negative* or receiving end or pole of the arrangement, and the alkali at the *positive* or delivering extremity.

468. Similar litmus and turmeric paper points were now placed upon glass plates, and connected by a string six feet long, both string and paper being moistened in solution of sulphate of soda; a needle point connected with the machine was brought opposite the litmus paper point, and another needle point connected with the discharging train brought opposite the turmeric paper. On working the machine, acid appeared on the litmus, and alkali on the turmeric paper; but the latter was not so abundant as in former cases, for much of the electricity passed off from the string into the air, and diminished the quantity discharged at the turmeric point.

469. Finally, a series of four small compound conductors, consisting of litmus and turmeric paper (fig. 5.) moistened in solution of sulphate of soda, were supported on glass rods, in a line at a little distance from each other, between the points *p* and *n* of the machine and discharging train, so that the electricity might pass in succession through them, entering in at the litmus points *b, b*, and passing out at the turmeric points *a, a*. On working the machine carefully, so as to avoid sparks and brushes (322.), I soon obtained evidence of decomposition in each of the moist conductors, for all the litmus points exhibited free acid, and the turmeric points equally showed free alkali.

470. On using solutions of iodide of potassium, acetate of lead, &c., similar effects were obtained; but as they were all consistent with the results above described, I refrain from describing the appearances minutely.

471. These cases of electro-chemical decomposition are in their nature exactly of the same kind as those effected under ordinary circumstances by the voltaic battery, notwithstanding the great differences as to the presence or absence, or at least as to the nature of the parts usually called poles; and also of the final situation of the elements eliminated at the boundary electrified surfaces (467.). They indicate at once an internal action of the parts suffering decomposition, and appear to show that the power which is effectual in separating the elements is exerted there, and not at the poles. But I shall defer the consideration of this point for a short time (493. 518.), that I may previously consider another supposed condition of electro-chemical decomposition*.

* I find (since making and describing these results,) from a note to Sir HUMPHRY DAVY's paper in the Philosophical Transactions, 1807, p. 31, that that philosopher, in repeating WOLLASTON's experiment of the decomposition of water by common electricity (327. 330.), used an arrangement somewhat like some of those I have described. He immersed a guarded platina point connected with the machine in distilled water, and dissipated the electricity from the water into the air by moistened filaments of cotton. In this way he states that he obtained oxygen and hydrogen *separately* from each other. This experiment, had I known of it, ought to have been quoted in an earlier series of these Researches (342.); but it does not remove any of the objections I have made to the use of WOLLASTON's apparatus as a test of true chemical action (331.).

¶ ii. *Influence of Water in Electro-chemical Decomposition.*

472. It is the opinion of several philosophers, that the presence of water is essential in electro-chemical decomposition, and also for the evolution of electricity by the voltaic battery itself. As the decomposing cell is merely one of the cells of the battery, into which particular substances are introduced for the purpose of experiment, it is probable that what is an essential condition in the one case is more or less so in the other. The opinion, therefore, that water is necessary to decomposition, may have been founded on the statement made by Sir HUMPHRY DAVY, that "there are no fluids known, except such as contain water, which are capable of being made the medium of connexion between the metals or metal of the voltaic apparatus*:" and again, "when any substance rendered fluid by heat, consisting of *water*, oxygen, and inflammable or metallic matter, is exposed to those wires, similar phenomena (of decomposition) occur†."

473. This opinion has, I think, been shown by other philosophers not to be accurate, though I do not know where to refer for a contradiction of it. Sir HUMPHRY DAVY himself said in 1801‡, that dry nitre, caustic potash and soda are conductors of galvanism when rendered fluid by a high degree of heat; but he must have considered them, or the nitre at least, as not suffering decomposition, for the statements above were made by him eleven years subsequently. In 1826 he also pointed out, that bodies not containing water, as *fused litharge* and *chlorate of potassa*, were sufficient to form, with platina and zinc, powerful electromotive circles§; but he is here speaking of the *production* of electricity in the pile, and not of its effects when evolved; nor do his words at all imply that any correction of his former distinct statements relative to *decomposition* was required.

474. I may refer to the last series of these Experimental Researches (380. 402.) as setting the matter at rest, by proving that there are hundreds of bodies equally influential with water in this respect. That amongst binary compounds, oxides, chlorides, iodides, and even sulphurets (402.) were effective; and

* Elements of Chemical Philosophy, p. 169, &c.

† Ibid. pp. 144, 145.

‡ Journal of the Royal Institution, 1802, p. 53.

§ Philosophical Transactions, 1826, p. 406.

that amongst more complicated compounds, cyanides and salts, of equal efficacy, occurred in great numbers (402.).

475. Water, therefore, is in this respect merely one of a very numerous class of substances, instead of being the *only one* and *essential*; and it is of that class one of the worst as to its capability of facilitating conduction and suffering decomposition. The reasons why it obtained for a time an exclusive character which it so little deserved are evident, and consist, in the general necessity of a fluid condition (394.); in its being the *only one* of this class of bodies existing in the fluid state at common temperatures; its abundant supply as the great natural solvent; and its constant use in that character in philosophical investigations, because of its having less interfering, injurious, or complicating action upon the bodies, either dissolved or evolved, than any other substance.

476. The analogy of the decomposing or experimental cell to the other cells of the voltaic battery, renders it nearly certain that any of those substances which are decomposable when fluid, as described in my last paper (402.), would, if they could be introduced between the metallic plates of the pile, be equally effectual with water, if not more so. Sir HUMPHRY DAVY found that litharge and chlorate of potassa were thus effectual*. I have constructed various voltaic arrangements, and found the above conclusion to hold good. When any of the following substances in a fused state were interposed between copper and platina, voltaic action more or less powerful was produced. Nitre; chlorate of potassa; carbonate of potassa; sulphate of soda; chloride of lead, of sodium, of bismuth, of calcium; iodide of lead; oxide of bismuth; oxide of lead: the electric current was in the same direction as if acids had acted upon the metals. When any of the same substances, or phosphate of soda, were made to act on platina and iron, still more powerful voltaic combinations of the same kind were produced. When either nitrate of silver or chloride of silver was the fluid substance interposed, there was voltaic action, but the electric current was in the reverse direction.

¶ iii. *Theory of Electro-chemical Decomposition.*

477. The extreme beauty and value of electro-chemical decompositions have given to that power which the voltaic pile possesses of causing their occur-

* Philosophical Transactions, 1826, p. 406.

rence an interest surpassing that of any other of its properties ; for the power is not only intimately connected with the continuance, if not the production, of the electrical phenomena, but has furnished us with the most beautiful demonstrations of the nature of many compound bodies ; has in the hands of **BECQUEREL** been employed in compounding bodies ; has given us several new substances, and sustains us with the hope that when thoroughly understood it will produce many more.

478. What may be considered as the general facts of electro-chemical decomposition are agreed to by nearly all who have written on the subject. They consist in the separation of the decomposable substance acted upon into its proximate or sometimes ultimate principles, whenever both poles of the pile are in contact with that substance in a proper condition ; in the evolution of these principles at distant points, i. e. at the poles of the pile where they are either finally set free or enter into union with the substance of the poles ; and in the constant determination of the evolved elements or principles to particular poles according to certain well ascertained laws.

479. But the views of men of science vary much as to the nature of the action by which these effects are produced ; and as it is certain that we shall be better able to apply the power when we really understand the manner in which it operates, this difference of opinion is a strong inducement to further inquiry. I have been led to hope that the following investigations might be considered, not as an increase of that which is doubtful, but a real addition to this branch of knowledge.

480. It will be needful that I briefly state the views of electro-chemical decomposition already put forth, that their present contradictory and unsatisfactory state may be seen before I give that which seems to me more accurately to agree with facts ; and I have ventured to discuss them freely, trusting that I should give no offence to their high-minded authors ; for I felt convinced that if I were right, they would be pleased that their views should serve as stepping-stones for the advance of science, and that if I were wrong, they would excuse the zeal which misled me, since it was exerted for the service of that great cause whose prosperity and progress they have desired.

481. **GROTHUSS**, in the year 1805, wrote expressly on the decomposition of
MDCCCXXXIII.

4 T

liquids by voltaic electricity*. He considers the pile as an electric magnet, i. e. as an *attractive* agent; the poles having *attractive* and *repelling* powers. The pole from whence resinous electricity issues attracts hydrogen and repels oxygen, whilst that from which vitreous electricity proceeds attracts oxygen and repels hydrogen; so that each of the elements of a particle of water, for instance, is subject to an attractive and a repulsive force, acting in contrary directions, the centres of action of which are reciprocally opposed. The action of each force in relation to a molecule of water situated in the course of the electric current is in the inverse ratio of the square of the distance at which it is exerted, thus giving (it is stated) for such a molecule a *constant force*†. He explains the appearance of the elements at a distance from each other by referring to a succession of decompositions and recompositions occurring amongst the intervening particles‡, and he thinks it probable that those which are about to separate at the poles unite to the two electricities there, and in consequence become gases§.

482. Sir HUMPHRY DAVY's celebrated Bakerian Lecture on some chemical agencies of electricity was read in November 1806, and is almost entirely occupied in the consideration of *electro-chemical decompositions*. The facts are of the utmost value, and, with the general points established, are universally known. The mode of action by which the effects take place is stated very generally, so generally, indeed, that probably a dozen precise schemes of electro-chemical action might be drawn up, differing essentially from each other, yet all agreeing with the statement there given.

483. When Sir HUMPHRY DAVY uses more particular expressions, he seems to refer the decomposing effects to the attractions of the poles. This is the case in the "general expression of facts" given at pp. 28 and 29 of the Philosophical Transactions for 1807, also at p. 30. Again, at p. 160 of the Elements of Chemical Philosophy, he speaks of the great attracting powers of the surfaces of the poles. He mentions the probability of a succession of decompositions and recompositions throughout the fluid,—agreeing in that respect with GROTHUSS||;

* Annales de Chimie, 1806, tom. lviii. p. 64.

† Ibid. pp. 66, 67, also tom. lxiii. p. 20.

‡ Ibid. tom. lviii. p. 68, tom. lxiii. p. 20.

§ Ibid. tom. lxiii. p. 34.

|| Philosophical Transactions, 1807, pp. 29, 30.

and supposes that the attractive and repellent agencies may be communicated from the metallic surfaces throughout the whole of the menstruum*, being communicated from *one particle to another particle of the same kind*†, and diminishing in strength from the place of the poles to the middle point, which is necessarily neutral‡. In reference to this diminution of power at increased distances from the poles, he states that in a circuit of ten inches of water, solution of sulphate of potassa placed four inches from the positive pole, did not decompose; whereas when only two inches from that pole, it did render up its elements§.

484. When in 1826 Sir HUMPHRY DAVY wrote again on this subject, he stated that he found nothing to alter in the fundamental theory laid down in the original communication||, and uses the terms attraction and repulsion apparently in the same sense as before¶.

485. MESSRS. RIFFAULT and CHOMPRÉ experimented on this subject in 1807. They came to the conclusion that the voltaic current caused decompositions throughout its whole course in the humid conductor, not merely as preliminary to the recompositions spoken of by GROTHUSS and DAVY, but producing final separation of the elements in the *course* of the current, and elsewhere than at the poles. They considered the *negative* current as collecting and carrying the acids, &c., to the *positive* pole, and the *positive* current as doing the same duty with the bases, and collecting them at the *negative* pole. They likewise consider the currents as *more powerful* the nearer they are to their respective poles, and state that the positive current is *superior* in power to the negative current**.

486. M. BIOT is very cautious in expressing an opinion as to the cause of the separation of the elements of a compound body††. But as far as the effects can be understood, he refers them to the opposite electrical states of the portions of the decomposing substance in the neighbourhood of the two poles. The fluid is most positive at the positive pole; that state gradually diminishes to the middle distance, where the fluid is neutral or not electrical; but from thence to the negative pole it becomes more and more negative‡‡. When a particle of salt

* Philosophical Transactions, 1807, p. 39.

† Ibid. p. 29.

‡ Ibid. p. 42.

§ Ibid. p. 42.

|| Ibid. 1826, p. 383.

¶ Ibid. pp. 389, 407, 415.

** Annales de Chimie, 1807, tom. lxxiii. p. 83, &c.

†† Précis Élémentaire de Physique, 3^{me} édition, 1824, tom. i. p. 641.

‡‡ Ibid. p. 637.

is decomposed at the negative pole, the acid particle is considered as acquiring a negative electrical state from the pole stronger than that of the surrounding *undecomposed* particles, and is therefore repelled from amongst them, and from out of that portion of the liquid towards the positive pole, towards which also it is drawn by the attraction of the pole itself and the particles of positive *undecomposed* fluid around it*.

487. M. BIOT does not appear to admit the successive decompositions and recompositions spoken of by GROTHUSS, DAVY, &c. &c.; but seems to consider the substance whilst in transit as combined with, or rather attached to, the electricity for the time†, and though it communicates this electricity to the surrounding undecomposed matter with which it is in contact, yet it retains during the transit a little superiority with respect to that kind which it first received from the pole, and is, by virtue of that difference, carried forward through the fluid to the opposite pole‡.

488. This theory implies that decomposition takes place at both poles upon distinct portions of fluid, and not at all in the intervening parts. The latter serve merely as imperfect conductors, which, assuming an electric state, urge particles electrified more highly at the poles through them in opposite directions, by virtue of a series of ordinary electrical attractions and repulsions§.

489. M. A. DE LA RIVE investigated this subject particularly, and published a paper on it in 1825||. He thinks those who have referred the phenomena to the attractive powers of the poles, express the fact generally, rather than give any explication of it. He considers the results as due to an actual combination of the elements, or rather of half of them, with the electricities passing from the poles in consequence of a kind of play of affinities between the matter and electricity¶. The current from the positive pole combining with the hydrogen, or the bases it finds there, leaves the oxygen and acids at liberty, but carries the substances it is united with across to the negative pole, where, because of the peculiar character of the metal as a conductor**, it is separated from them, entering the metal, and leaving the hydrogen or bases upon its surface. In the same manner the electricity from the negative pole sets the

* Précis Élémentaire de Physique, 3^{me} édition, 1824, tom. i. pp. 641, 642.

† Ibid. p. 636.

‡ Ibid. p. 642.

§ Ibid. pp. 638, 642.

|| Annales de Chimie, tom. xxviii. p. 190.

¶ Ibid. pp. 200, 202.

** Ibid. p. 202.

hydrogen and bases which it finds there, free, but combines with the oxygen and acids, carries them across to the positive pole, and there deposits them *. In this respect M. DE LA RIVE's hypothesis accords in part with that of MM. RIFFAULT and CHOMPRÉ (485.).

490. M. DE LA RIVE considers the portions of matter which are decomposed to be those contiguous to *both* poles†. He does not admit with others the successive decompositions and recompositions in the whole course of the electricity through the humid conductor‡, but thinks the middle parts are in themselves unaltered, or at least serve only to conduct the two contrary currents of electricity and matter which set off from the opposite poles §. The decomposition, therefore, of a particle of water, or a particle of salt, may take place at either pole, and when once effected, it is final for the time, no recombination taking place, except the momentary union of the transferred particle with the electricity be so considered.

491. The latest communication that I am aware of on the subject is by M. HACHETTE: its date is October 1832||. It is incidental to the description of the decomposition of water by the magneto-electric currents (346.). One of the results of the experiment is, that "it is not necessary, as has been supposed, that for the chemical decomposition of water, the action of the two electricities, positive and negative, should be simultaneous."

492. It is more than probable that many other views of electro-chemical decomposition may have been published, and perhaps amongst them some which, differing from those above, might, even in my own opinion, were I acquainted with them, obviate the necessity for the publication of my views. If such be the case, I have to regret my ignorance of them, and apologize to the authors.

493. That electro-chemical decomposition does not depend upon any direct attraction and repulsion of the poles (meaning thereby the metallic terminations either of the voltaic battery, or ordinary electrical machine arrangements (312.),) upon the elements in contact with or near to them, appeared very evident from the experiments made in air (462, 465, &c.), when the substances evolved did not collect about any poles, but, in obedience to the direction

* Annales de Chimie, tom. xxviii. p. 201.

† Ibid. pp. 197, 198.

‡ Ibid. pp. 192, 199.

§ Ibid. p. 200.

|| Ibid. tom. li. p. 73.

of the current, were evolved, and I would say ejected, at the extremities of the decomposing substance. But notwithstanding the extreme dissimilarity in the character of air and metals, and the almost total difference existing between them as to their mode of conducting electricity, and becoming charged with it, it might perhaps still be contended, although quite hypothetically, that the bounding portions of air were now the surfaces or places of attraction, as the metals had been supposed to be before. In illustration of this and other points, I endeavoured to devise an arrangement by which I could decompose a body against a surface of water, as well as against air or metal, and succeeded in doing so unexceptionably in the following manner. As the experiment for very natural reasons requires many precautions, to be successful, and will be referred to hereafter in illustration of the views I shall venture to give, I must describe it minutely.

494. A glass basin (fig. 6.), four inches in diameter and four inches deep, had a division of mica *a*, fixed across the upper part so as to descend one inch and a half below the edge, and be perfectly water-tight at the sides: a plate of platina *b*, three inches wide, was put into the basin on one side of the division *a*, and retained there by a glass block below, so that any gas produced by it in a future stage of the experiment should not ascend beyond the mica, and cause currents in the liquid on that side. A strong solution of sulphate of magnesia was carefully poured without splashing into the basin, until it rose a little above the lower edge of the mica division *a*, great care being taken that the glass or mica on the unoccupied or *c* side of the division in the figure, should not be moistened by agitation of the solution above the level to which it rose. A thin piece of clean cork, well wetted in distilled water, was then carefully and lightly placed on the solution at the *c* side, and distilled water poured gently on to it until a stratum the eighth of an inch in thickness appeared over the sulphate of magnesia; all was then left for a few minutes, that any solution adhering to the cork might sink away from it, or be removed by the water on which it now floated; and then more distilled water was added in a similar manner, until it reached nearly to the top of the glass. In this way solution of the sulphate occupied the lower part of the glass, and also the upper on the right hand side of the mica; but on the left hand side of the division a stratum of water from *c* to *d*, one inch and a half in depth, reposed upon it,

the two presenting, when looked through horizontally, a very definite plane of contact. A second platina pole *e*, was arranged so as to be just under the surface of the water, in a position nearly horizontal, a little inclination being given to it, that gas evolved during decomposition might escape: the part immersed was three inches and a half long by one inch wide, and about seven eighths of an inch of water intervened between it and the solution of sulphate of magnesia.

495. The latter pole *e* was now connected with the negative end of a voltaic battery, of forty pairs of plates four inches square, whilst the former pole *b* was connected with the positive end. There was action and gas evolved at both poles; but from the intervention of the pure water, the decomposition was very feeble compared to what the battery would have effected in a uniform solution. After a little while (less than a minute,) magnesia also appeared at the negative side: *it did not make its appearance at the negative pole*, but in the water, at the plane where the solution and the water met; and on looking at it horizontally, it could be there perceived lying in the water upon the solution, not rising more than the fourth of an inch above the latter, whilst the water between it and the negative pole was perfectly clear. On continuing the action, the bubbles of hydrogen rising upwards from the negative pole impressed a circulatory movement on the stratum of water, upwards in the middle, and downwards at the side, which gradually gave an ascending form to the cloud of magnesia in the part just under the pole, having an appearance as if it were there attracted to it; but this was altogether an effect of the currents, and did not occur until long after the phenomena required were satisfactorily ascertained.

496. After a little while the voltaic communication was broken, and the platina poles removed with as little agitation as possible from the water and solution, for the purpose of examining the liquid adhering to them. The pole *e*, when touched by turmeric paper, gave no traces of alkali, nor could anything but pure water be found upon it. The pole *b*, though drawn through a much greater depth and quantity of fluid, was found so acid as to give abundant evidence to litmus paper, the tongue, and other tests. Hence there had been no interference of alkaline salts in any way, undergoing first decomposition, and then causing the separation of the magnesia at a distance from the pole by mere chemical agencies.

This experiment was repeated again and again, and always successfully.

497. As, therefore, the substances evolved in cases of electro-chemical decomposition may be made to appear against air (465. 469.),—which, according to common language, is not a conductor, nor is decomposed; or against water (495.), which is a conductor, and can be decomposed,—as well as against the metal poles, which are excellent conductors, but undecomposable, there appears but little reason to consider the phenomena generally, as due to the *attraction* or attractive powers of the latter, when used in the ordinary way, since similar attractions can hardly be imagined in the former instances.

498. It may be said that the surfaces of air or of water in these cases become the poles, and exert attractive powers; but what proof is there of that, except the fact that the matters evolved collect there, which is the point to be explained, and cannot be justly quoted as its own explanation? Or it may be said, that any section of the humid conductor, as that in the present case, where the solution and the water meet, may be considered as representing the pole. But such does not appear to me to be the view of those who have written on the subject, certainly not of some of them, and is inconsistent with the supposed laws which they have assumed, as governing the diminution of power at increased distances from the poles.

499. GROTHUSS, for instance, describes the poles as centres of attractive and repulsive forces (481), these forces varying inversely as the squares of the distances, and says, therefore, that a particle placed anywhere between the poles will be acted upon by a constant force. But the compound force, resulting from such a combination as he supposes, would be anything but a constant force; it would evidently be a force greatest at the poles, and diminishing to the middle distance. GROTHUSS is right, however, *in the fact*, according to my experiments (502. 505.), that the particles are acted upon by equal force everywhere in the circuit, when the conditions of the experiment are the simplest possible; but the fact is against his theory, and is also, I think, against all theories that place the decomposing effect in the attractive power of the poles.

500. Sir HUMPHRY DAVY, who also speaks of the *diminution* of power with increase of distance from the poles * (483.), supposes, that when both poles are acting on substances to decompose them, still the power of decomposition

* Philosophical Transactions, 1807, p. 42.

diminishes to the middle distance. In this statement of fact he is opposed to GROTHUSS, and quotes an experiment in which sulphate of potassa, placed at different distances from the poles in a humid conductor of constant length, decomposed when near the pole, but not when at a distance. Such a consequence would necessarily result theoretically from considering the poles as centres of attraction and repulsion; but I have not found the statement borne out by other experiments (505.); and in the one quoted by him the effect was doubtless due to some of the many interfering causes of variation which attend such investigations.

501. A glass vessel had a platina plate fixed perpendicularly across it, so as to divide it into two cells: a head of mica was fixed over it, so as to collect the gas it might evolve during experiments; then each cell, and the space beneath the mica, was filled with dilute sulphuric acid. Two poles were provided, consisting each of a platina wire terminated by a plate of the same metal; each was fixed into a tube passing through its upper end by an air-tight joint, that it might be moveable, and yet that the gas evolved at it might be collected. The tubes were filled with the acid, and one immersed in each cell. Each platina pole was equal in surface to one side of the dividing plate in the middle glass vessel, and the whole might be considered as an arrangement between the poles of the battery of a humid decomposable conductor divided in the middle by the interposed platina diaphragm. It was easy, when required, to draw one of the poles further up the tube, and then the platina diaphragm was no longer in the middle of the humid conductor. But whether it were thus arranged at the middle, or towards one side, it always evolved a quantity of oxygen and hydrogen equal to that evolved by both the extreme plates*.

502. If the wires of a galvanometer be terminated by plates, and these be immersed in dilute acid, contained in a regularly formed rectangular glass trough, connected at each end with a voltaic battery by poles equal to the section of the fluid, a part of the electricity will pass through the instrument and cause a certain deflection. And if the plates are always retained at the same distance from each other and from the sides of the trough, are always parallel to each

* There are certain precautions, in this and such experiments, which can only be understood and guarded against by a knowledge of the phenomena to be described in the first part of the Sixth Series of these Researches.

other, and uniformly placed relative to the fluid, then, whether the galvanometer plates are immersed near the middle of the decomposing solution, or near one end, still the instrument will indicate the same deflection, and consequently the same electric influence.

503. It is very evident that when the width of the decomposing conductor varies, as is always the case when mere wires or plates, as poles, are dipped into or are surrounded by solution, no constant expression can be given as to the action upon a single particle placed in the course of the current, nor any conclusion of use relative to the supposed attractive or repulsive force of the poles be drawn. The force will vary as the distance from the pole varies; as the particle is directly between the poles, or more or less on one side; and even as it is nearer to or further from the sides of the containing vessels, or as the shape of the vessel itself varies; and, in fact, by making variations in the form of the arrangement, the force upon any single particle may be made to increase, or diminish, or remain constant, whilst the distance between the particle and the pole shall remain the same; or the force may be made to increase, or diminish, or remain constant, either as the distance increases or as it diminishes.

504. From numerous experiments, I am led to believe the following general expression to be correct; but I purpose examining it much further, and would therefore wish not to be considered at present as pledged to its accuracy. The sum of chemical decomposition is constant for any section taken across a decomposing conductor, uniform in its nature, at whatever distance the poles may be from each other or from the section; or however that section may intersect the currents, whether directly across them, or so oblique as to reach almost from pole to pole, or whether it be plane, or curved, or irregular in the utmost degree; provided the current of electricity be retained constant in quantity (377.), and that the section include all portions of the current through the decomposing conductor.

505. I have reason to believe that the statement might be made still more general, and expressed thus: That for a constant quantity of electricity, whatever the decomposing conductor may be, whether water, saline solutions, acids, fused bodies, &c., the amount of electro-chemical action is also a constant quantity, i. e. would always be equivalent to a standard chemical effect founded

upon ordinary chemical affinity. I have this investigation in hand, with several others, and shall be prepared to give it in the next series but one of these Researches.

506. Many other arguments might be adduced against the hypotheses of the attraction of the poles being the cause of electro-chemical decomposition; but I would rather pass on to the view I have thought more consistent with facts, with this single remark; that if decomposition by the voltaic battery depended upon the attraction of the poles, or the parts about them, being stronger than the mutual attraction of the particles separated, it would follow that the weakest electrical attraction was stronger than, if not the strongest yet, very strong chemical attraction, namely, such as exists between oxygen and hydrogen, potassium and oxygen, chlorine and sodium, acid and alkali, &c., a consequence which, although perhaps not impossible, seems in the present state of the subject very unlikely.

507. The view which M. DE LA RIVE has taken (489.), and also MM. RIFFAULT and CHOMPRÉ (485), of the manner in which electro-chemical decomposition is effected, is very different to that already considered, and is not affected by either arguments or facts against the latter. Considering it as stated by the former philosopher, it appears to me to be incompetent to account for the experiments of decomposition against surfaces of air (462. 469.) and water (495.), which I have described; for if the physical differences between metals and humid conductors, which M. DE LA RIVE supposes to account for the transmission of the compound of matter and electricity in the latter, and the transmission of the electricity only with the rejection of the matter in the former, be allowed for a moment, still the relation of air to metal is, electrically considered, so small, that instead of the former replacing the latter (462.), an effect the very reverse might have been expected. Or if even that were allowed, the experiment with water (495.), at once sets the matter at rest, the decomposing pole being now of a substance which is admitted as competent to transmit the compound of electricity and matter.

508. With regard to the views of MM. RIFFAULT and CHOMPRÉ (485.), the occurrence of deposition in the course of the current is so contrary to the well known effects obtained in the forms of experiment adopted up to this time, that it must be proved before the hypothesis depending on it need be considered.

509. The consideration of the various theories of electro-chemical decomposition, whilst it has made me diffident, has also given me confidence to add another to the number; for it is because the one I have to propose appears, after the most attentive consideration, to explain and agree with the immense collection of facts belonging to this branch of science, and to remain uncontradicted by, or unopposed to, any of them, that I have been encouraged to give it.

510. Electro-chemical decomposition is well known to depend essentially upon the *current* of electricity. I have shown that in certain cases (375.) the decomposition is proportionate to the quantity of electricity passing, whatever may be its intensity or its source, and that the same is probably true for all cases (377.), even when the utmost generality is taken on the one hand, and great precision of expression on the other.

511. In speaking of the current, I find myself obliged to be still more particular than on a former occasion (283.), in consequence of the variety of views taken by philosophers, all agreeing in the effect of the current itself. Some philosophers, with FRANKLIN, assume but one electric fluid; and such must agree together in the general uniformity and character of the electric current. Others assume two electric fluids; and here singular differences have arisen.

512. MM. RIFFAULT and CHOMPRÉ, for instance, consider the positive and negative currents each as causing decomposition, and state that the positive current is *more powerful* than the negative current*, the nitrate of soda being, under similar circumstances, decomposed by the former, but not by the latter.

513. M. HACHETTE states† that “it is not necessary, as has been believed, that the action of the two electricities, positive and negative, should be simultaneous for the decomposition of water.” The passage implying, if I have caught the meaning aright, that one electricity can be obtained, and can be applied in effecting decompositions, independent of the other.

514. The view of M. DE LA RIVE to a certain extent agrees with that of M. HACHETTE, for he considers that the two electricities decompose separate portions of water (490.)‡. In one passage he speaks of the two electricities as two influences, wishing perhaps to avoid offering a decided opinion upon the independent existence of electric fluids; but as these influences are consi-

* Annales de Chimie, 1807, tom. lxiii. p. 84.

† Ibid. 1832, tom. li. p. 73.

‡ Ibid. 1825, tom. xxviii. pp. 197, 201.

dered as combining with the elements set free as by a species of chemical affinity, and for the time entirely masking their character, great vagueness of idea is thus introduced, inasmuch as such species of combination can only be conceived to take place between things having independent existence. The two elementary electric currents, moving in opposite directions, from pole to pole, constitute the ordinary *voltaic current*.

515. M. GROTHUSS is inclined to believe that the elements of water, when about to separate at the poles, combine with the electricities, and so become gases. M. DE LA RIVE's view is the exact reverse of this: whilst passing through the fluid, they are, according to him, compounds with the electricities; when evolved at the poles, they are de-electrified.

516. I have sought amongst the various experiments quoted in support of these views, or connected with electro-chemical decompositions or electric currents, for any which might be considered as sustaining the theory of two electricities rather than that of one, but have not been able to perceive a single fact which could be brought forward for such a purpose: or, admitting the hypothesis of two electricities, much less have I been able to perceive the slightest grounds for believing that one electricity in a current can be more powerful than the other, or that it can be present without the other, or that one can be varied, or in the slightest degree affected, without a corresponding variation in the other. If, upon the supposition of two electricities, a current of one can be obtained without the other, or the current of one be exalted or diminished more than the other, we might surely expect some variation either of the chemical or magnetical effects, or of both; but no such variations have been observed. If a current be so directed that it may act chemically in one part of its course, and magnetically in another, the two actions are always found to take place together. A current has not, to my knowledge, been produced which could act chemically and not magnetically, nor any which can act on the magnet, and not *at the same time* chemically*.

517. *Judging from facts only*, there is not as yet the slightest reason for considering the influence which is present in what we call the electric current,—whether in metals or fused bodies or humid conductors, or even in air, flame,

* Thermo-electric currents are of course no exception, because when they fail to act chemically they also fail to be currents.

and rarefied elastic media,—as a compound or complicated influence. It has never been resolved into simpler or elementary influences, and may perhaps best be conceived of as *an axis of power having contrary forces, exactly equal in amount, in contrary directions.*

518. Passing to the consideration of electro-chemical decomposition, it appears to me that the effect is produced by an *internal corpuscular action*, exerted according to the direction of the electric current; and that it is due to a force either *superadded to*, or *giving direction to the ordinary chemical affinity* of the bodies present. The decomposing body may be considered as a mass of acting particles, all those which are included in the course of the electric current contributing to the final effect; and it is because the ordinary chemical affinity is relieved, weakened, or partly neutralized by the influence of the electric current in one direction, parallel to the course of the latter, and strengthened or added to in the opposite direction, that the combining particles have a tendency to pass in opposite courses.

519. In this view the effect is considered as *essentially dependent* upon the *mutual chemical affinity* of the particles of opposite kinds. Particles *a a*, fig. 7, could not be transferred or travel from one pole N towards the other P, unless they found particles of the opposite kind *b b*, ready to pass in the contrary direction: for it is by virtue of their increased affinity for those particles, combined with their diminished affinity for such as are behind them in their course, that they are urged forward: and when any one particle *a*, fig. 8, arrives at the pole, it is excluded or set free, because the particle *b* of the opposite kind, with which it was the moment before in combination, has, under the superinducing influence of the current, a greater attraction for the particle *a'*, which is before it in its course, than for the particle *a*, towards which its affinity has been weakened.

520. As far as regards any single compound particle, the case may be considered as analogous to one of ordinary decomposition, for in fig. 8, *a* may be conceived to be expelled from the compound *a b* by the superior attraction of *a'* for *b*, that superior attraction belonging to it in consequence of the relative position of *a' b* and *a* to the direction of the axis of electric power (517.) superinduced by the current. But as all the compound particles in the course of the current, except those actually in contact with the poles, act conjointly, and consist of elementary particles, which, whilst they are in one direction

expelling, are in the other being expelled, the case becomes more complicated, but not more difficult of comprehension.

521. It is not here assumed that the acting particles must be in a right line between the poles. The lines of action which may be supposed to represent the electric currents passing through a decomposing liquid, have in many experiments very irregular forms; and even in the simplest case of two wires or points immersed as poles in a drop, or larger single portion of fluid, these lines must diverge rapidly from the poles; and the direction in which the chemical affinity between particles is most powerfully modified (519. 520.) will vary with the direction of these lines, according constantly with them. But even in reference to these lines or currents, it is not supposed that the particles which mutually affect each other must of necessity be parallel to them, but only that they shall accord generally with their direction. Two particles, placed in a line perpendicular to the electric current passing in any particular place, are not supposed to have their ordinary chemical relations towards each other affected; but as the line joining them is inclined one way to the current, their mutual affinity is increased; as it is inclined in the other direction, it is diminished; and the effect is a maximum, when that line is parallel to the current.

522. That the actions, of whatever kind they may be, take place frequently in oblique directions is evident from the circumstance of those particles being included which in numerous cases are not in a line between the poles. Thus, when wires are used as poles in a glass of solution, the decompositions and recompositions occur to the right or left of the direct line between the poles, and indeed in every part to which the currents extend, as is proved by many experiments, and must therefore often occur between particles obliquely placed as respects the current itself; and when a metallic vessel containing the solution is made one pole, whilst a mere point or wire is used for the other, the decompositions and recompositions must frequently be still more oblique to the course of the currents.

523. The theory which I have ventured to put forth (almost) requires an admission, that in a compound body capable of electro-chemical decomposition the elementary particles have a mutual relation to, and influence upon each other, extending beyond those with which they are immediately combined. Thus in water, a particle of hydrogen in combination with oxygen is considered

as not altogether indifferent to other particles of oxygen, although they are combined with other particles of hydrogen; but to have an affinity or attraction towards them, which, though it does not at all approach in force, under ordinary circumstances, to that by which it is combined with its own particle, can under the electric influence, exerted in a definite direction, be made even to surpass it. This general relation of particles already in combination to other particles with which they are not combined, is sufficiently distinct in numerous results of a purely chemical character, especially in those where partial decompositions only take place, and in BERTHOLLET's experiments on the effects of quantity upon affinity; and it probably has a direct relation to, and connexion with, attraction of aggregation, both in solids and fluids. It is a remarkable circumstance, that in gases and vapours, where the attraction of aggregation ceases, there likewise the decomposing powers of electricity apparently cease, and there also the chemical action of quantity is no longer evident. It seems not unlikely, that the inability to suffer decomposition in these cases may be dependent upon the absence of that mutual attractive relation of the particles which is the cause of aggregation.

524. I hope I have now distinctly stated, although in general terms, the view I entertain of the cause of electro-chemical decomposition, as far as that cause can at present be traced and understood. I conceive the effects to arise from forces which are *internal*, relative to the matter under decomposition—and not *external*, as they might be considered, if directly dependent upon the poles. I suppose that the effects are due to a modification, by the electric current, of the chemical affinity of the particles through or by which that current is passing, giving them the power of acting more forcibly in one direction than in another, and consequently making them travel by a series of successive decompositions and recompositions in opposite directions, and finally causing their expulsion or exclusion at the boundaries of the decomposing body, in the direction of the current, and *that* in larger or smaller quantities, according as the current is more or less powerful (377.). I think, therefore, it would be more philosophical, and more directly expressive of the facts, to speak of a decomposing body, in relation to the current passing through it, rather than to the poles, as they are usually called, in contact with it; and say that whilst under decomposition, oxygen, chlorine, iodine, acids, &c., are rendered at the

negative extremity, and combustibles, metals, alkalies, bases, &c., at the positive extremity of the decomposing substance (467.). I do not believe that a substance can be transferred in the electric current beyond the point where it ceases to find particles with which it can combine; and I may refer to the experiments made in air (465.), and in water (495.), already quoted, for facts illustrating these views in the first instance; to which I will now add others.

525. In order to show the dependence of the decomposition and transfer of elements upon the chemical affinity of the substances present, experiments were made upon sulphuric acid in the following manner. Dilute sulphuric acid was prepared: its specific gravity was 1021.2. A solution of sulphate of soda was also prepared, of such strength that a measure of it contained exactly as much sulphuric acid as an equal measure of the diluted acid just referred to. A solution of pure soda, and another of pure ammonia, were likewise prepared, of such strengths that a measure of either should be exactly neutralized by a measure of the prepared sulphuric acid.

526. Four glass cups were then arranged, as in fig. 9; seventeen measures of the free sulphuric acid (525.) were put into each of the vessels *a* and *b*, and seventeen measures of the solution of sulphate of soda into each of the vessels A and B. Asbestos, which had been well washed in acid, acted upon by the voltaic pile, well washed in water, and dried by pressure, was used to connect *a* with *b* and A with B, the portions being as equal as they could be made in quantity, and cut as short as was consistent with their performing the part of effectual communications. *b* and A were connected by two platina plates or poles soldered to the extremities of one wire, and the cups *a* and B were by similar platina plates connected with a voltaic battery of forty pairs of plates four inches square, that in *a* being connected with the negative, and that in B with the positive pole. The battery, which was not powerfully charged, was retained in communication above half an hour. In this manner it was certain that the same electric current had passed through *a b* and A B, and that in each instance the same quantity and strength of acid had been submitted to its action, but in one case merely dissolved in water, and in the other dissolved and also combined with an alkali.

527. On breaking the connexion with the battery, the portions of asbestos were lifted out, and the drops hanging at the ends allowed to fall each into its

respective vessel. The acids in *a* and *b* were then first compared, for which purpose two evaporating dishes were balanced, and the acid from *a* put into one, and that from *b* into the other; but as one was a little heavier than the other, a small drop was transferred from the heavier to the lighter, and the two rendered equal in weight. Being neutralized by addition of the soda solution (525.), that from *a*, or the negative vessel, required 15 parts of the soda solution, and that from *b*, or the positive vessel, required 16.3 parts. That the sum of these is not 34 parts is principally due to the acid removed with the asbestos; but, taking the mean of 15.65 parts, it would appear that a twenty-fourth part of the acid originally in the vessel *a* had passed, through the influence of the electric current, from *a* into *b*.

528. In comparing the difference of acid in A and B, the necessary equality of weight was considered as of no consequence, because the solution was at first neutral, and would not, therefore, affect the test liquids, and all the evolved acid would be in B, and the free alkali in A. The solution in A required 3.2 measures of the prepared acid (525.) to neutralize it, and the solution in B required also 3.2 measures of the soda solution (525.) to neutralize it. As the asbestos must have removed a little acid and alkali from the glasses, these quantities are by so much too small; and therefore it would appear that about a tenth of the acid originally in the vessel A had been transferred into B during the continuance of the electric action.

529. In another similar experiment, whilst a thirty-fifth part of the acid passed from *a* to *b* in the free acid vessels, between a tenth and an eleventh passed from A to B in the combined acid vessels. Other experiments of the same kind gave similar results.

530. The variation of electro-chemical decomposition, the transfer of elements and their accumulation at the poles, according as the substance submitted to action consists of particles opposed more or less in their chemical affinity, together with the consequent influence of the latter circumstances, are sufficiently obvious in these cases, where sulphuric acid is acted upon in the *same quantity* by the *same* electric current, but in one case opposed to the comparatively weak affinity of water for it, and in the other to the stronger one of soda. In the latter case the quantity transferred is from two and a half to three times what it is in the former; and it appears therefore very evident that

the transfer is greatly dependent upon the mutual action of the particles of the decomposing bodies.

531. In some of the experiments the acid from the vessels *a* and *b* was neutralized by ammonia, then evaporated to dryness, heated to redness, and the residue examined for sulphates. In these cases more sulphate was always obtained from *a* than from *b*; showing that it had been impossible to exclude saline bases (derived from the asbestos, the glass, or perhaps impurities originally in the acid,) and that they had helped in transferring the acid into *b*. But the quantity was small, and the acid was principally transferred by relation to the water present.

532. I endeavoured to arrange certain experiments by which saline solutions should be decomposed against surfaces of water; and at first worked with the electric machine upon a piece of bibulous paper, or asbestos moistened in the solution, and in contact at its two extremities with pointed pieces of paper moistened in pure water, which served to carry the electric current to and from the solution in the middle piece. But I found numerous interfering difficulties. Thus, the water and solutions in the pieces of paper could not be prevented from mingling at the point where they touched. Again, sufficient acid could be derived from the paper connected with the discharging train, or it may be even from the air itself, under the influence of electric action, to neutralize the alkali developed at the positive extremity of the decomposing solution, and so not merely prevent its appearance, but actually transfer it on to the metal termination: and, in fact, when the paper points were not allowed to touch there, and the machine was worked until alkali was evolved at the delivering or positive end of the turmeric paper, containing the sulphate of soda solution, it was merely necessary to place the opposite receiving point of the paper connected with the discharging train, which had been moistened by distilled water, upon the browned turmeric point and press them together, when the alkaline effect immediately disappeared.

533. The experiment with sulphate of magnesia already described (495.) is a case in point, however, and shows most clearly that the sulphuric acid and magnesia contributed to each other's transfer and final evolution, exactly as the same acid and soda affected each other in the results just given (527, &c.); and that so soon as the magnesia advanced beyond the reach of the acid, and

found no other substance with which it could combine, it appeared in its proper character, and was no longer able to continue its progress towards the negative pole.

534. The theory I have ventured to put forth appears to me to explain all the prominent features of electro-chemical decomposition in a satisfactory manner.

535. In the first place it explains why, in all ordinary cases, the evolved substances appear only at the poles; for the poles are the limiting surfaces of the decomposing substance, and except at them, every particle finds other particles having a contrary tendency with which it can combine.

536. Then it explains why, in numerous cases, the elements or evolved substances are not *retained* by the poles; and this is no small difficulty in those theories which refer the decomposing effect directly to the attractive power of the poles. If a piece of platina have sufficient power given to it by any means to attract a particle of hydrogen from the particle of oxygen with which it was the instant before combined, there seems no sufficient reason, nor any fact, except those to be explained, which show why it should not, according to analogy with all ordinary attractive forces, as those of gravitation, the magnet, cohesion, chemical affinity, &c., *retain* that particle which it had just before taken from a distance and from previous combination. Yet it does not do so, but allows it to escape freely. Nor does this depend upon its assuming the gaseous state, for acids and alkalies, &c., are left equally at liberty to diffuse themselves through the fluid surrounding the pole, and show no particular tendency to combine with or cleave to the latter. And though there are plenty of cases where combination with the pole does take place, they do not at all explain the instances of non-combination, and do not therefore in their particular action reveal the general principle of decomposition.

537. But in the theory that I have just given, the effect appears to be a natural consequence of the action: the evolved substances are expelled from the decomposing mass (518. 519.), not *drawn out by an attraction* which ceases to act on one particle without any assignable reason, while it continues to act on another of the same kind: and whether the poles be metal, water, or air, still the substances are evolved, and sometimes are set free, or sometimes unite to the matter of the poles, according to the chemical nature of the latter, i. e. the chemical relation of their particles to those which are leaving the substance under operation.

538. The theory accounts for the transfer of elements in a manner which seems to me at present to leave nothing unexplained ; and it was, indeed, the phenomena of transfer in the numerous cases of decomposition of bodies rendered fluid by heat (380. 402.), which, in conjunction with the experiments in air, led to its construction. Such cases as the former where binary compounds of easy decomposability are acted upon, are perhaps the best to illustrate the theory.

539. Chloride of lead, for instance, fused in a bent tube (400.), and decomposed by platina wires, evolves lead, passing to what is usually called the negative pole, and chlorine, which being evolved at the positive pole, is in part set free, and in part combines with the platina. The chloride formed, being soluble in the chloride of lead, is subject to decomposition, and the platina itself is gradually transferred across the decomposing matter, and found with the lead at the negative pole.

540. Iodide of lead evolves abundance of lead at the negative pole, and abundance of iodine at the positive pole.

541. Chloride of silver furnishes a beautiful instance, especially when decomposed by silver wire poles. Upon fusing a portion of it on a piece of glass, and bringing the poles into contact with it, there is abundance of silver evolved at the negative pole, and an equal abundance absorbed at the positive pole, for no chlorine is set free; and by careful management, the negative wire may be withdrawn from the fused globule as the silver is reduced there, the latter serving as the continuation of the pole, until a wire or thread of revived silver, five or six inches in length, is produced ; at the same time the silver at the positive pole is as rapidly dissolved by the chlorine, which seizes upon it, so that the wire has to be continually advanced as it is melted away. The whole experiment includes the action of only two elements, silver and chlorine, and illustrates in a beautiful manner their progress in opposite directions, parallel to the electric current, which is for the time giving a uniform general direction to their mutual affinities (524.).

542. According to my theory, an element or a substance not decomposable under the circumstances of the experiment, (as, for instance, a dilute acid or alkali,) should not be transferred, or pass from pole to pole, unless it be in chemical relation to some other element or substance tending to pass in the opposite direction, for the effect is considered as essentially due to the mutual

relation of such particles. But the theories attributing the determination of the elements to the attractions and repulsions of the poles require no such condition, i. e. there is no reason apparent why the attraction of the positive pole, and the repulsion of the negative pole, upon a particle of free acid, placed in water between them, should not (with equal currents of electricity) be as strong as if that particle were previously combined with alkali; but, on the contrary, as they have not a powerful chemical affinity to overcome, there is every reason to suppose they would be stronger, and would sooner bring the acid to rest at the positive pole*. Yet such is not the case, as has been shown by the experiments on free and combined acid (526. 528.).

543. Neither does M. DE LA RIVE's theory, as I understand it, require that the particles should be in combination: it does not even admit, where there are two sets of particles capable of combining with and passing by each other, that they do combine, but supposes that they travel as separate compounds of matter and electricity. Yet in fact, the free substance *cannot* travel, the combined one *can*.

544. It is very difficult to find cases amongst solutions or fluids which shall illustrate this point, because of the difficulty of finding two fluids which shall conduct, shall not mingle, and in which an element evolved from one shall not find a combinable element in the other. Solutions of acids or alkalies will not answer, because they exist by virtue of an attraction; and increasing the solubility of a body in one direction, and diminishing it in the opposite, is just as good a reason for transfer, as modifying the affinity between the acid and alkali themselves. Nevertheless the case of sulphate of magnesia is in point (494. 495.), and shows that one element or principle only has no power of transference or of passing towards either pole.

545. Many of the metals, however, in their solid state, offer very fair instances of the kind required. Thus, if a plate of platina be used as the positive pole in a solution of sulphuric acid, oxygen will pass towards it, and so will acid; but these are not substances having such chemical relation to the platina as, even under the favourable condition superinduced by the current (518. 524.), to combine with it; the platina therefore remains where it was first placed, and has

* Even Sir HUMPHRY DAVY considered the attraction of the pole as being communicated from one particle to another of the *same* kind (483.).

no tendency to pass towards the negative pole. But if a plate of iron, zinc or copper, be substituted for the platina, then the oxygen and acid can combine with these, and the metal immediately begins to travel as an oxide, to the opposite pole, and is finally deposited there. Or if, retaining the platina pole, a fused chloride, as of lead, zinc, silver, &c., be substituted for the sulphuric acid, then, as the platina finds an element it can combine with, it enters into union, acts as other elements do in cases of voltaic decomposition, is rapidly transferred across the melted matter, and expelled at the negative pole.

546. I can see but little reason in the theories referring the electro-chemical decomposition to the attractions and repulsions of the poles, and I can perceive none in M. DE LA RIVE's theory, why the metal of the positive pole should not be transferred across the intervening conductor, and deposited at the negative pole, even when it cannot act chemically upon the element of the fluid surrounding it. It cannot be referred to the attraction of cohesion preventing such an effect; for if the pole be made of the lightest spongy platina, the effect is the same. Or if gold precipitated by sulphate of iron be diffused through the solution, still accumulation of it at the negative pole will not take place; and yet in it the attraction of cohesion is almost perfectly overcome, the particles are so small as to remain for hours in suspension, and are perfectly free to move by the slightest impulse towards either pole; and *if in relation* by chemical affinity to any substance present, are powerfully determined to the negative pole*.

547. In support of these arguments, it may be observed, that as yet no determination of a substance to a pole, or tendency of obedience to the electric current, has been observed (that I am aware of,) in cases of mere mixture; i. e. a substance diffused through a fluid, but having no sensible chemical affinity with it, or with substances that may be evolved from it during the action,

* In making this experiment, care must be taken that no substance be present that can act chemically on the gold. Although I used the metal very carefully washed, and diffused through dilute sulphuric acid, yet in the first instance I obtained gold at the negative pole, and the effect was repeated when the platina poles were changed. But on examining the clear liquor in the cell, after subsidence of the metallic gold, I found a little of that metal in solution, and a little chlorine was also present. I therefore well washed the gold which had thus been subjected to voltaic action, diffused it through other pure dilute sulphuric acid, and then found that on subjecting it to the action of the poles, not the slightest tendency to the negative pole could be perceived.

does not in any case seem to be affected by the electric current. Pulverised charcoal was diffused through dilute sulphuric acid, and subjected with the solution to the action of a voltaic battery, terminated by platina poles; but not the slightest tendency of the charcoal to the negative pole could be observed. Sublimed sulphur was diffused through similar acid, and submitted to the same action, a silver plate being used as the negative pole; but the sulphur had no tendency to pass to that pole, the silver was not tarnished, nor did any sulphuretted hydrogen appear. The case of magnesia and water (495. 533.), with those of comminuted metals in certain solutions (546.), are also of this kind; and, in fact, substances which have the instant before been powerfully determined towards the pole, as magnesia from sulphate of magnesia, become entirely indifferent to it the moment they assume their independent state, and pass away, diffusing themselves in the surrounding fluid.

548. There are, it is true, many instances of insoluble bodies being acted upon, as glass, sulphate of baryta, marble, slate, basalt, &c., but they form no exception; for the substances they give up are in direct and strong relation as to chemical affinity with those which they find in the surrounding solution, so that these decompositions enter into the class of ordinary effects.

549. It may be expressed as a general consequence, that the more directly bodies are opposed to each other in chemical affinity, the more *ready* is their separation from each other in cases of electro-chemical decomposition, i. e. provided other circumstances, as insolubility, deficient conducting power, proportions, &c., do not interfere. This is well known to be the case with water and saline solutions; and I have found it to be equally true with *dry* chlorides, iodides, salts, &c., rendered subject to electro-chemical decomposition by fusion (402.). So that in applying the voltaic battery for the purpose of decomposing bodies not yet resolved into forms of matter simpler than their own, it must be remembered, that success may depend not upon the weakness, or failure upon the strength, of the affinity by which the elements sought for are held together, but contrariwise; and then modes of application may be devised by which, in *association* with ordinary chemical powers, and the assistance of fusion (394. 417.), we may be able to penetrate much further than at present into the constitution of our chemical elements.

550. Some of the most beautiful and surprising cases of electro-chemical

decomposition and transfer which Sir HUMPHRY DAVY described in his celebrated paper*, were those in which acids were passed through alkalies, and alkalies or earths through acids†; and the way in which substances having the most powerful attractions for each other were thus prevented from combining, or, as it is said, had their natural affinity destroyed or suspended throughout the whole of the circuit, excited the utmost astonishment. But if I be right in the view I have taken of the effects, it will appear, that that which made the *wonder*, is in fact the *essential condition* of transfer and decomposition, and that the more alkali there is in the course of an acid, the more will the transfer of that acid be facilitated from pole to pole; and perhaps a better illustration of the difference between the theory I have ventured, and those previously existing, cannot be offered than the views they respectively give of such facts as these.

551. The instances in which sulphuric acid could not be passed through baryta, or baryta through sulphuric acid‡, because of the precipitation of sulphate of baryta, enter within the pale of the law already described (380. 412.), by which liquidity is so generally required. In assuming the solid state of sulphate of baryta, they became virtually non-conductors to electricity of so low a tension as that of the voltaic battery, and the power of the latter over them was almost infinitely diminished.

552. The theory I have advanced accords in a most satisfactory manner with the fact of an element or substance finding its place of rest, or rather of evolution, sometimes at one pole and sometimes at the other. Sulphur illustrates this effect very well. When sulphuric acid is decomposed by the pile, sulphur is evolved at the negative pole; but when sulphuret of silver is decomposed in a similar way (436.), then the sulphur appears at the positive pole; and if a hot platina pole be used so as to vaporize the sulphur evolved in the latter case, then the relation of that pole to the sulphur is exactly the same as the relation of the same pole to oxygen upon its immersion in water. In both cases the element evolved is liberated at the pole, but not retained by it; but by virtue of its elastic, uncombinable, and immiscible condition passes away into the surrounding medium. The sulphur is evidently determined in these opposite directions by its opposite chemical relations to oxygen and silver; and it is to such relations generally that I have referred all electro-chemical phenomena.

* Philosophical Transactions, 1807, p. 1.

† Ibid. p. 24, &c.

‡ Ibid. p. 25, &c.

Where they do not exist, no electro-chemical action can take place. Where they are strongest, it is most powerful ; where they are reversed, the direction of transfer of the substance is reversed with them.

553. *Water* may be considered as one of those substances which can be made to pass to *either* pole. When the poles are immersed in dilute sulphuric acid (527.), acid passes towards the positive pole, and water towards the negative pole ; but when they are immersed in dilute alkali, the alkali passes towards the negative pole, and water towards the positive pole.

554. Nitrogen is another substance which is considered as determinable to either pole ; but in consequence of the numerous compounds which it forms, some of which pass to one pole and some to the other, I have not always found it easy to determine the true circumstances of its appearance. A pure strong solution of ammonia is so bad a conductor of electricity that it is scarcely more decomposable than pure water ; but if sulphate of ammonia be dissolved in it, then decomposition takes place very well, nitrogen almost pure, and in some cases quite, is evolved at the positive pole, and hydrogen at the negative pole.

555. On the other hand, if a strong solution of nitrate of ammonia be decomposed, oxygen appears at the positive pole, and hydrogen, with sometimes nitrogen, at the negative pole. If fused nitrate of ammonia be employed, hydrogen appears at the negative pole, mingled with a little nitrogen. Strong nitric acid yields plenty of oxygen at the positive pole, but no gas (only nitrous acid,) at the negative pole. Weak nitric acid yields the oxygen and hydrogen of the water present, the acid apparently remaining unchanged. Strong nitric acid, with nitrate of ammonia dissolved in it, yields a gas at the negative pole, of which the greater part is hydrogen, but apparently a little nitrogen is present. I believe, that in some of these cases a little nitrogen appeared at the negative pole. I suspect, however, that in all these, and in all former cases, the appearance of the nitrogen at the positive or negative pole is entirely a secondary effect, and not an immediate consequence of the decomposing power of the electric current.

556. A few observations on what are called the *poles* of the voltaic battery now seem necessary. The poles are merely the surfaces or doors by which the electricity enters into or passes out of the decomposing substance. They limit the extent of that substance in the course of the electric current, being its

termination in that direction: hence the elements evolved pass so far and no further.

557. Metals make admirable poles, in consequence of their high conducting power, their immiscibility with the substances generally acted upon, their solid form, and the opportunity afforded of selecting some upon which ordinary substances exert no chemical action.

558. Water makes a pole of difficult application, except in a few cases (494.), because of its small conducting power, its miscibility with most of the substances acted upon, and its general relation to them in respect to chemical affinity. It consists of elements, which in their electrical and chemical relations are directly and powerfully opposed, yet combining to produce a body more neutral in its character than any other. So that there are but few substances which do not come into relation, by chemical affinity, with water or one of its elements; and therefore either the water or its elements are transferred and assist in transferring the infinite variety of bodies which, in association with it, can be placed in the course of the electric current. Hence the reason why it so rarely happens that the evolved substances rest at the first surface of the water, and why it therefore does not exhibit the ordinary action of a pole.

559. Air, however, and some gases are free from the latter objection, and may be used as poles in many cases (461, &c.); but, in consequence of the extremely low degree of conducting power belonging to them, they cannot be employed with the voltaic apparatus. This limits their use; for the voltaic apparatus is the only one as yet discovered which supplies sufficient quantity of electricity (371. 376.) to effect electro-chemical decomposition with facility.

560. Where the poles are liable to the chemical action of the substances evolved, either simply in consequence of their natural relation to them, or of that relation aided by the influence of the current (518.), then they suffer corrosion, and the parts dissolved are subject to transference, in the same manner as particles of the original decomposing body. An immense series of phenomena of this kind might be quoted in support of the view I have taken of the cause of electro-chemical decomposition, and transfer and evolution of the elements. Thus platina, as the positive and negative poles in a solution of sulphate of soda, has no affinity or attraction for the oxygen, hydrogen, acid, or alkali evolved, and refuses to combine with or retain them. Zinc can com-

bine with the oxygen and acid; at the positive pole it does combine, and immediately begins to travel as oxide towards the negative pole. Charcoal, which cannot combine with the metals, if made the negative pole in a metallic solution, refuses to unite to the bodies which are ejected from the solution upon its surface; but if made the positive pole in a dilute solution of sulphuric acid, it is capable of combining with the oxygen evolved there, and consequently unites with it, producing both carbonic acid and carbonic oxide in abundance.

561. A great advantage is frequently supplied, by the opportunity afforded amongst the metals of selecting a substance for the pole which shall or shall not be acted upon by the elements to be evolved. The consequent use of platina is notorious. In the decomposition of sulphuret of silver and other sulphurets, a positive silver pole is superior to a platina one, because in the former case the sulphur evolved there is combined with the silver, and the decomposition of the original sulphuret rendered evident; whereas in the latter case it is dissipated, and the assurance of its separation at the pole not easily obtained.

562. The effects which take place when a succession of conducting decomposable and undecomposable substances are placed in the electric circuit, as, for instance, of wires and solutions, or of air and solutions (465. 469.), are explained in the simplest possible manner by the view I have given. In consequence of the reaction of the constituents of each portion of decomposable matter, affected as they are by the supervention of the electric current (524.), portions of the proximate or ultimate elements proceed in the direction of the current as far as they find matter of a contrary kind capable of effecting their transfer, and being equally affected by them; and where they cease to find such matter, they are evolved in their free state, i. e. upon the surfaces of metal or air bounding the extent of decomposable matter in the direction of the currents.

563. Having thus given my theory of the mode in which electro-chemical decomposition is effected, I will refrain for the present from entering upon the numerous general considerations which it suggests, wishing first to submit it to the test of publication and discussion.

Royal Institution,
June 1833.

XXIX. *The Anatomy and Physiology of the Liver.* By FRANCIS KIERNAN, Esq., Member of the Royal College of Surgeons, late Teacher of Anatomy. Communicated by J. H. GREEN, Esq., F.R.S.

Received June 20,—Read June 20, 1833.

THE small bodies of which the liver is composed, and which have been known to anatomists, since the time of MALPIGHI, by the various names of acini, lobules, corpuscula, glandular grains and granulations, were discovered by WEPFER in the liver of the pig about two years before the appearance of MALPIGHI's celebrated work *De Viscerum Structurâ Exercitatio Anatomica*. WEPFER contented himself with indicating the existence of the lobules in one animal*. MALPIGHI, unacquainted, as it would appear, with WEPFER's discovery, commenced his researches on the lower animals, and pursuing them through every class, ascertained that a similar arrangement of structure existed in all. In shell-fish, he says†, the lobules resemble bunches of grapes, and are composed of small conglobate bodies, like grape-stones, which are connected together by means of central vessels. He observed a similar conformation in lizards, in which animals the edges and interstices of the lobules are denoted by dark points. After describing the liver of the ferret, mouse, squirrel and ox, he informs us that the human liver also is composed of lobules, which represent a congeries of clusters, and may be rendered apparent by boil-

* I have not been able to find WEPFER's Work: his words, as quoted by MALPIGHI, *Opera Posthuma*, p. 32, Londini 1697, and by PORTAL, *Histoire de l'Anatomie*, tom. iii. p. 243, are—"Expendas euge hepar suillum coctum: inuenies detractâ extimâ membranâ, totam et vastam hanc molem, quasi ex innumeris glandulis combinatam. In aliis jecoribus, fateor, nondum observavi: sed fracto suillo bene cocto vidi glandulas quadrangulares, aliterque ratione figuræ affectas. Perlectis Clarissimi NICOLAI STENONIS observationibus cogitavi, quia et hepar quasi conglomerata est, an fortè hepatis officium foret lympham suo modo præparare ad usus corporis utiles, eamque juxta bilem secernere?"—*De Dubiis Anatomicis, Epistola ad JACOB. HEN. PAULUM*. Norimberg 1664.

† *De Hepate*, cap. 2.

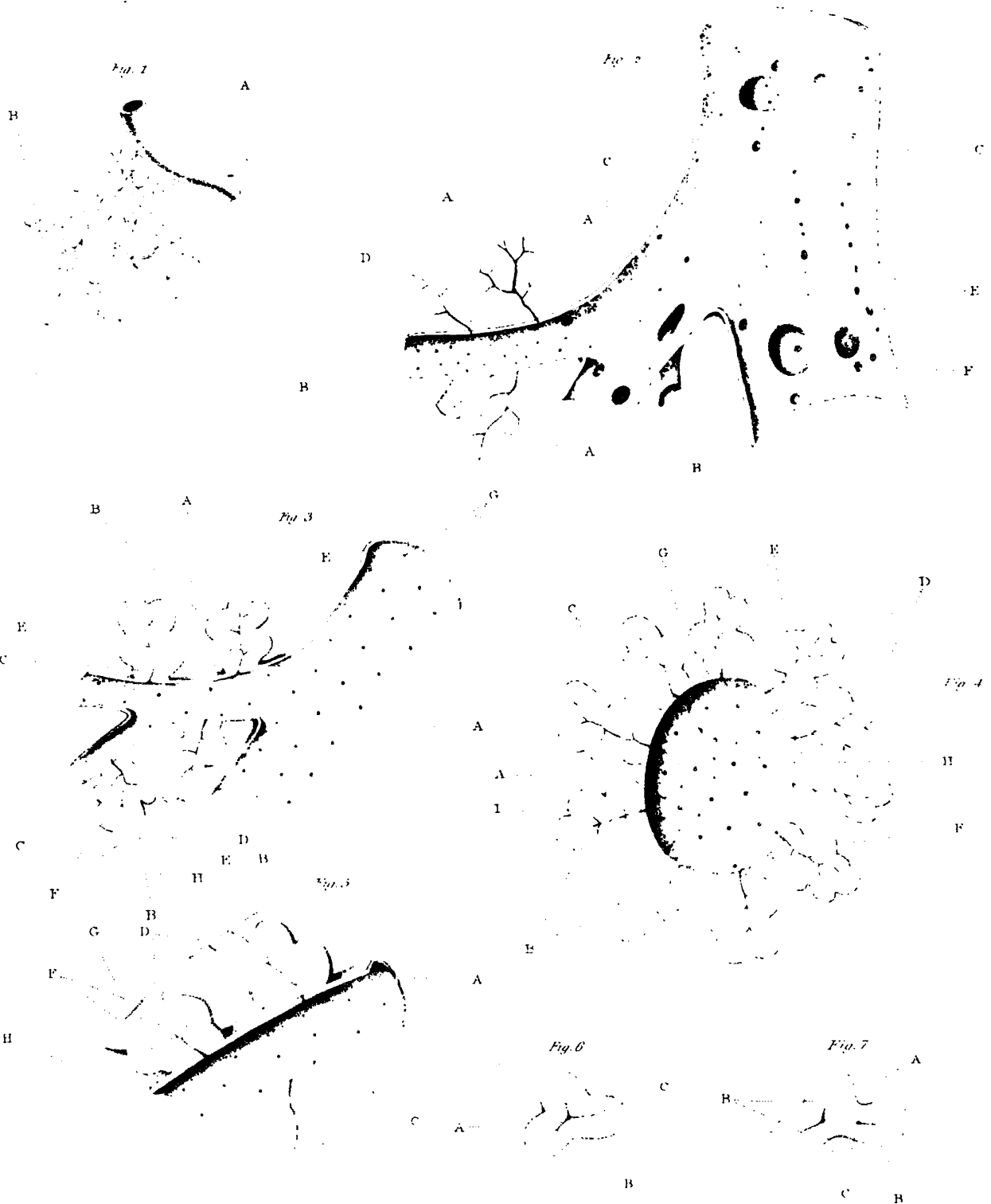
ing the organ and taking off its external coat. The lobules, he says, are appended to the extremities of the vessels contained in Glisson's capsule, and are invested in membranous tunics connected together by transverse bands. They vary in form in different animals: in fishes they resemble the leaf of the trefoil; in some animals they are pisiform; in the cat they have six or more sides; and they assume the hexagonal form in the human liver. Biliary calculi found in the liver were thought by MALPIGHI to be petrified lobules. Respecting the structure of the lobules, MALPIGHI informs us, that the glandular acini of which these bodies are composed have six or more sides; that they are connected by their vessels and bound together by proper membranes, the interstices between them being very apparent in the lower animals and in fishes, but obscure in the higher animals. MALPIGHI, having thus convinced himself of the existence of glandular acini in the liver, similar to those already known in the pancreas and thymus, classed this organ among the conglomerate glands*; but as he gave no representations by plates of the important discoveries he made, some difficulty has been experienced in understanding his descriptions†. Thus, he speaks of two kinds of bodies, of lobules and of acini: anatomists‡, however, having used these terms indifferently to designate the same objects, have not understood them in the sense in which they were employed by MALPIGHI. MALPIGHI's discoveries in the anatomy of the liver are almost confined to the ascertaining its lobulated structure: he was unacquainted with the form of the lobules, with their peculiar arrangement around the hepatic veins, and with the manner in which the vessels are distributed; nor has much light been thrown on these points by the researches of more modern anatomists, although very considerable additions have been lately made to our knowledge of the ultimate

* De Hepate, cap. 3.

† The lobules and acini, as described by MALPIGHI, have been delineated by MASCAGNI, *Prodromo della grande Anatomia*, tab. vi. figg. 13, 14, 17. They have been also represented by BIDLOO, *Anatomia Corporis Humani*, tab. 38. fig. 1. The same figure will be found in COWPER's *Anatomy of Humane Bodies*.

‡ "On peut donner le nom de *lobules (acini)* aux petits amas de substance médullaire et de substance corticale réunies."—MECKEL, *Anatomie Générale Descriptive et Pathologique*, tom. iii. p. 453.

"M. FERRIN a trouvé dans chaque grain ou lobule du foye deux substances différentes."—Mémoires de l'Académie Royale des Sciences, Histoire. 1733. SÄMMERING also, in speaking of the lobules, calls them *acini*.



structure of the liver and of other glands by the important discoveries of MÜLLER*.

The following pages contain an account of my own investigations of the structure of this organ. The description I propose to give will embrace, 1st, that of the lobules, the manner of their arrangement, their connexions with each other and with the vessels; 2ndly, the surfaces of the liver and the distribution of the vessels; and 3rdly, the structure of the lobules.

Of the Lobules.—The hepatic veins with the lobules present a tolerably accurate resemblance to the trunk, branches and leaves of a tree. (Plate XX. fig. 1.) The lobules may be compared to the leaves. The substance of the lobules is arranged around the minute branches of the veins in a manner which may be compared to the disposition of the parenchyma of a leaf around its fibres. The vessels in which the minute veins terminate may be compared to the branches of the tree, and these vessels by their junction form the trunks. The hepatic veins may be divided into two classes; into those veins contained in the lobules, and those contained in canals formed by the lobules. The first class is composed of the intralobular branches, one of which occupies the centre of each lobule, and receives the blood from a plexus formed in the lobule by the portal vein. (Plate XX. fig. 2, a.) The second class of hepatic veins is composed of all those vessels contained in canals formed by the lobules. Numerous small branches, as well as the large trunks which terminate in the inferior cava, are included in this class; they all resemble each other in being contained in canals, and they differ from the vessels of the first class which are contained in the lobules. The intralobular veins terminate in some of these vessels, and not in others; these vessels therefore admit of being divided into two sets; 1st, those in which the intralobular branches terminate (Plate XX. fig. 2, b.); 2nd, those in which no intralobular branches terminate (Plate XX. fig. 2, c.). The lobules are arranged around the veins composing the first set, the bases of these bodies resting upon them; they may be called the sublobular-hepatic veins, this term being applied to them merely to distinguish them from the trunks which compose the second set, and on which the bases of the lobules do not rest. The branches of the second set are formed by the junc-

* De Glandularum secretorium Structurâ penitiori earumque primâ Formatione in Homine atque in Animalibus. Lipsiæ 1830.

tion of those of the first ; the canals containing the former differ in the manner of their formation from those containing the latter. Every branch of the hepatic veins contained in the liver belongs to one of these two classes of vessels.

Each intralobular vein is composed of a central vessel, and of from four to six or eight smaller vessels, which terminate in the central vessel. (Plate XX. fig. 3, *e. f.*) The intralobular veins invariably correspond in form with the lobules, the substance of which is arranged around them ; and as these vessels resemble in some degree the fibres of a leaf, so sections of the lobules made in the direction of the vessels assume a more or less foliated appearance. (Plate XX. fig. 3, *b.*) The lobules are not, however, flattened bodies like leaves ; for, as the smaller veins enter the central vein in every direction, so small processes project in every direction from the lobules, the number of processes being equal to the number of veins terminating in the central vein. The form of the lobules will be now easily understood ; their dimensions are known to all anatomists. They are small bodies, arranged in close contact around the sublobular-hepatic veins, each presenting two surfaces. One surface of every lobule, which may be called its base, rests upon a sublobular vein, to which it is connected by the intralobular vein running through its centre, the base of the lobule thus entering into the formation of the canal in which the sublobular vein is contained. (Plate XX. figg. 3. and 4, *c.*) The canals containing the hepatic veins may be called the hepatic-venous canals or surfaces ; and as the base of every lobule rests on a sublobular vein, it is evident that the canals containing these veins are formed by the bases of all the lobules of the liver. (Plate XX. fig. 4, *h.*) The external or capsular surface of every lobule (Plate XX. figg. 3. and 4, *d.*) is covered by an expansion of Glisson's capsule, by which it is connected to, and separated from, the contiguous lobules, and in which branches of the hepatic duct, portal vein and hepatic artery ramify. All the lobules resemble each other in their general form, and they are all of nearly equal dimensions ; they appear larger when the section is made in the direction of the hepatic veins, and smaller when in the transverse direction. This is most apparent in that state of the liver usually called the nutmeg liver. In a longitudinal section of a lobule, the intralobular vein is seen running through its centre ; and if on the surface of the section five of the projecting

processes of the lobule be seen, five smaller veins will also be seen, one occupying the centre of each process, and all terminating in the central vein. (Plate XX. figg. 3. and 4, *f*.) In a transverse section of a lobule, the divided extremity of the intralobular vein is seen in the centre, and three or four processes of the lobule are seen shooting out in different directions. (Plate XX. fig. 6.) The vein being thus always situated in the centre, it sometimes happens that on the surface of a section of the liver, veins are seen in some lobules and not in others; this appearance is caused by the instrument, which, passing obliquely through these lobules, divides some vessels, which thus become apparent, and passes either above or below others.

The superficial differ in one respect from the internal lobules. In the latter, the intralobular veins commence at a certain distance from the surfaces of these bodies, the substance of which completely surrounds them, except at the bases of the lobules, where the veins make their exit to terminate in the sublobular veins. (Plate XX. fig. 5, *c*.) By superficial lobules are meant, not those only which form the convex and concave surfaces, but those also the capsular surfaces of which form the canals containing certain branches of the hepatic duct, portal vein, and hepatic artery, and the canals containing the trunks of the hepatic veins, all these canals being tubular inflections inwards of the superficies of the liver. In all the superficial lobules, the intralobular veins commence immediately at the surfaces; these lobules appearing less perfect in form, or less developed, than those of the interior, or as if their upper portions had been removed, giving to the surfaces of the organ the appearance of the surface of a section. (Plate XX. fig. 5, *d*.) The knowledge of this peculiar form of the superficial lobules enables us, in injecting the hepatic veins, to limit the injection to this system of vessels, which is effected by withdrawing the syringe when the injection appears in minute points on the surface of the liver. If the injection be propelled from the hepatic veins into those portions of the lobular venous plexuses immediately surrounding the intralobular veins, the first stage of hepatic venous congestion will be simulated; this is effected by withdrawing the syringe when the injection appears in small isolated patches on the surface. The next stage of congestion will be simulated by propelling the injection until the patches partially coalesce, and become continuous with each other; and finally, the appearance of general congestion is produced when the injection

passes into those branches of the portal vein which ramify in the interlobular fissures. Occasionally double lobules, or lobules having two intralobular veins, are observed on the surface. (Plate XX. fig. 7.)

MASCAGNI *, adopting MALPIGHI's view of the arrangement of the lobules, compares the liver to a bunch of grapes; and this anatomist and BIDLOO have represented the lobules appended to the extremities of the vena portæ. As certain branches of this vein first ramify between the lobules, and finally enter them, these bodies may be represented as appended to its extremities: and although every lobule receives branches from this vein, yet a certain number only are clustered around its trunks, with which they have no immediate connexion; whereas the base of every lobule in the liver is in contact with, and connected to, an hepatic vein.

The essential part of a gland is undoubtedly its duct; vessels it possesses in common with every other organ; and it may be thought that in the above description too much importance is attached to the hepatic veins: but relations similar to those which exist between these veins and the lobules, do not exist between the latter and the ducts, or between them and any other set of vessels; nor is there the same exact relation between the ducts and lobules as between these bodies and the hepatic veins, for a lobule with six projecting processes may have three times that number of ducts ramifying on its external surface, whereas the same lobule will have but six minute veins, one in each process, all of which terminate in the central intralobular vein.

The foliated appearances delineated by MÜLLER †, resemble very closely the lobules as I have described them; but they are not lobules, nor are they described as such by this anatomist. The figure representing the structure of the liver of the squirrel resembles longitudinal sections of lobules in some parts, and transverse sections in other parts. Vessels similar in their course to the intralobular branches of the hepatic veins are seen in this figure; but the vessels here represented are interlobular branches of the portal vein; and had the duct and artery been injected, small branches of these vessels also would have been seen accompanying the branches of the vein. The vein is seen occupying a fissure, which at intervals is dilated into spaces; these, as will be shown, are the interstices between the lobules. In those parts of the same figure which

* Prodomo, p. 142. tab. vi. fig. 17.

† Op. cit. tab. xi. figg. 8, 9, 11.

Fig 1

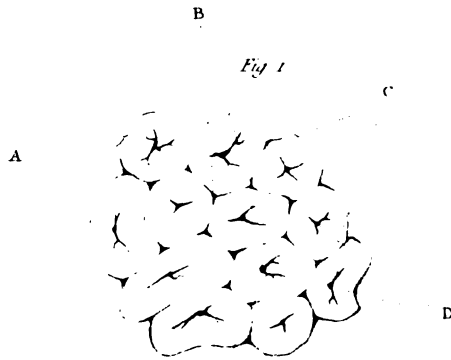


Fig 2

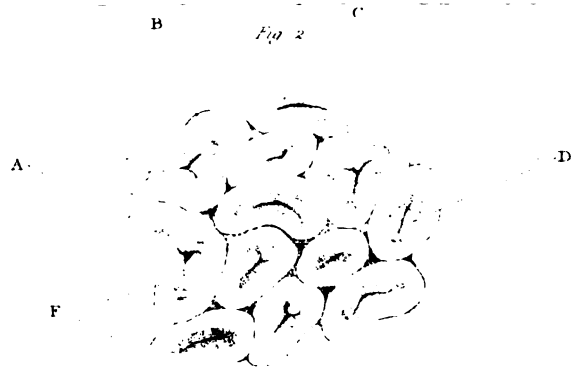


Fig 3

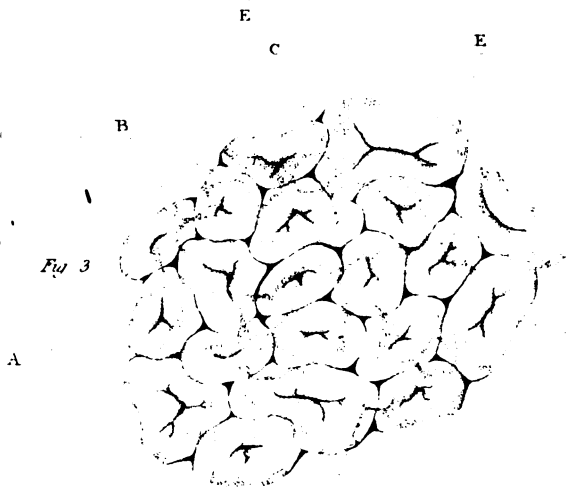


Fig 4

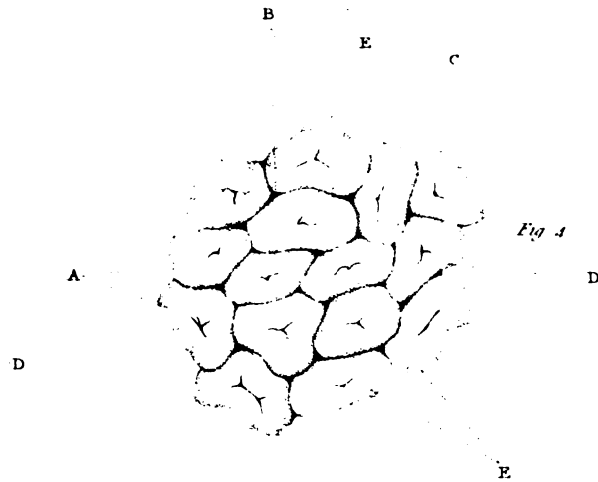


Fig 5

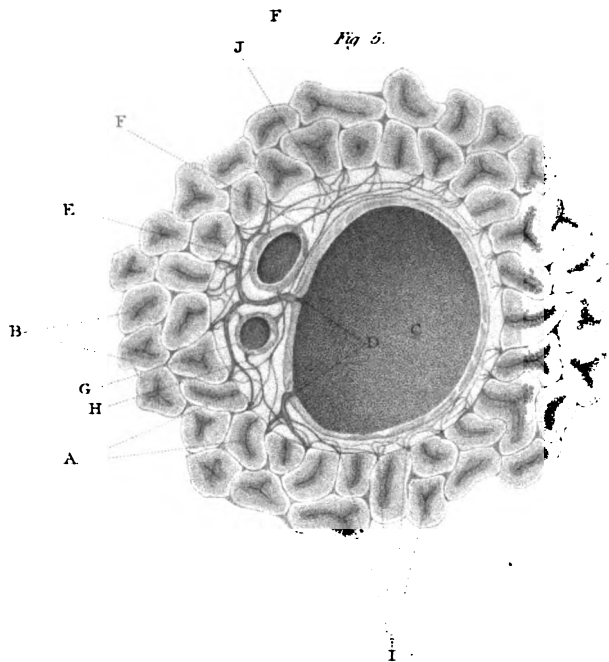
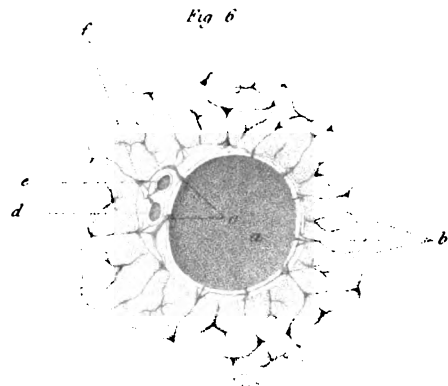


Fig 6



resemble transverse sections of lobules, the central dark spot is an interlobular space, occupied by branches of the duct, portal vein and hepatic artery. Had the animal died from hemorrhage, or had the portal vein and hepatic artery been tied in the living animal, so as to deprive the liver of its blood, no such appearances would have presented themselves, the arrangement of the structure of the liver in this, and in all the vertebrated animals, being much alike. I have preparations accurately exhibiting these appearances, which very commonly present themselves in the human liver, as well as in the liver of animals, and are produced by congestion, principally of the hepatic veins, the lobules being also congested except at their opposed margins. The same remarks apply to the delineations given by this anatomist of the liver of the quail, and to that of a portion of the human liver.

Of the Surfaces of the Liver.—The surfaces of the liver are, 1st, the external surface; 2ndly, the portal surfaces or canals, at which the vessels enter the organ; 3rdly, the hepatic-venous surfaces or canals, at which the vessels make their exit.

Of the External Surface.—Examined on the external surface of the liver, the lobules present every variety of form; but in one subject they may all be more or less angular, and in another rounded. They are separated from each other by fissures, which, at the angles of the lobules, dilate into small triangular spaces; they may be called the interlobular fissures and spaces; they contain the interlobular branches of the portal vein, hepatic artery and hepatic duct, ramifying in a fine cellular tissue continuous with Glisson's capsule, which, with the vessels, constitutes the capsules of the lobules. (Plate XXI. fig. 1, *b* and *c*.) The fissures and spaces were known to MALPIGHI: he was of opinion that by their means the liver is rendered flexible, and he tells us they are large in fishes, "qui flexuosè incedunt." He also informs us that the fissures were known to his predecessor CORTESIUS*, to FERNELIUS†, to GLISSON‡, and others.

* "Hic enim foramina quædam, seu rimulas in jecoris carne deprehendit."—De Hepate, cap. 2.

† "FERNELIUS rimulas in hepatis parenchymate observavit."—Ib.

‡ GLISSON appears to allude to the clefts so frequently seen on the surface of the liver, and not to the interlobular fissures. "Vidi aliquando in gibba quorundam jecinorum parte rimas et hiatus majusculos qui fortè à partium extremarum violentiore complicatione ortum duxerant: quemadmodum et panis frustrum nimîa incurvatione diffingitur."—Anatomia Hepatis, cap. 9.

MAPPES * has described the fissures and spaces; but this anatomist is mistaken in supposing that some of them contain hepatic veins alone, and that others contain hepatic veins, arteries and ducts. When there is but little cellular tissue in the capsules, the lobules are closely compacted together; they are therefore angular in form, and the fissures and spaces are less apparent. (Plate XXI. fig. 1.) Hence it is that these bodies have been described as having six or more sides by MALPIGHI, SÆMMERRING †, and others. But when the cellular tissue composing the capsules is more abundant, the fissures, and particularly the spaces containing it, are wider and more apparent; the lobules are less closely connected, they touch each other by two or three points only, and consequently approach more or less to the circular or oval form. (Plate XXI. fig. 2.) Hence they have been described as, and present very much the appearance of, convolutions and undulating bands ‡. They are generally angular where they are most numerous, as in the thickest part of the liver; in these parts also they appear smaller, for being arranged vertically to the surface, their extremities alone are seen. At the edges of the liver, where they are fewer in number and less closely connected, they are rounded; and lying in an oblique or parallel direction to the surface, they appear larger. They are more angular in children than in adults: in some animals, as in the cat, they are always more angular than in others, as in the rabbit, hare and sheep; their angular or rounded form always depending on the quantity of cellular tissue composing Glisson's capsule. They appear smaller, are more equal in size and regular in form on the convex than on the concave surface of the liver, where they are arranged obliquely, the hepatic veins for the most part running nearer to this surface.

* "Au milieu de toutes les circonvolutions de cette substance (la substance jaune) se trouvent la plupart du temps des ouvertures triangulaires, ou un peu frangées, qui communiquent les unes avec les autres par de petites fentes."—*Quelques Considérations sur la Structure du Foie*,—*Journal Complémentaire des Sciences Médicales*, tom. xii. p. 223.

† "Idem, si in superficie aut in plagâ aliquâ dissectâ attentius consideraveris, ex acinis parvis quodammodo triquetris, tetragonis, pentagonis, hexagonis ac multangulis compositum videtur."—*De Corporis Humani Fabricâ*, vol. vi. p. 175.

‡ "L'une de ces substances, qu'on peut appeler granulée (médullaire suivant AUTENRIETH), forme des circonvolutions, tantôt semblables à celles des intestins, tantôt rameuses, plates et arrondies."—MAPPES, loc. cit.

An intralobular hepatic vein occupies the centre of each superficial lobule *. If the extremity alone of a lobule reach the surface, a mere point will be seen in its centre; if a greater portion of the lobule be seen, two or three dark lines will be observed uniting together at a dark point; this point is the central intralobular vein in which the smaller veins terminate. (Plate XXI. fig. 1, *d* and *e*.) Frequently, lobules with eight or ten projecting processes are found on the surface, each process sending a vein to the intralobular vein running through the centre. It is evident that these superficial lobules are less perfect in form or less developed than the internal lobules, in which the veins are wholly surrounded by the substance (Plate XX. fig. 5, *d*.); and that a superficial lobule with eight or ten processes is, accurately speaking, half a lobule lying parallel to the surface. Lobules lying parallel to the surface may be always seen on the under and posterior part of the left lobe; such lobules are larger and more numerous in the liver of the sheep, rabbit, hare and squirrel than in the human liver. (Plate XX. fig. 1.) A striking difference will be observed if, in the liver of the sheep, these parallel lobules on the posterior part of the concave surface be contrasted with those forming the lobulus Spigelii. The difference between the superficial and internal lobules is satisfactorily proved by injections. If the hepatic veins be injected with blue size, and the portal vein with red, the blue will be found on the surface of every section, in the centres of the lobules, separated by the substance of these bodies from the portal veins occupying the interlobular fissures. If these lobules were, like those of the surfaces, perforated from one extremity to the other by the intralobular veins, the blue and red injection, or the intralobular hepatic veins and the interlobular portal

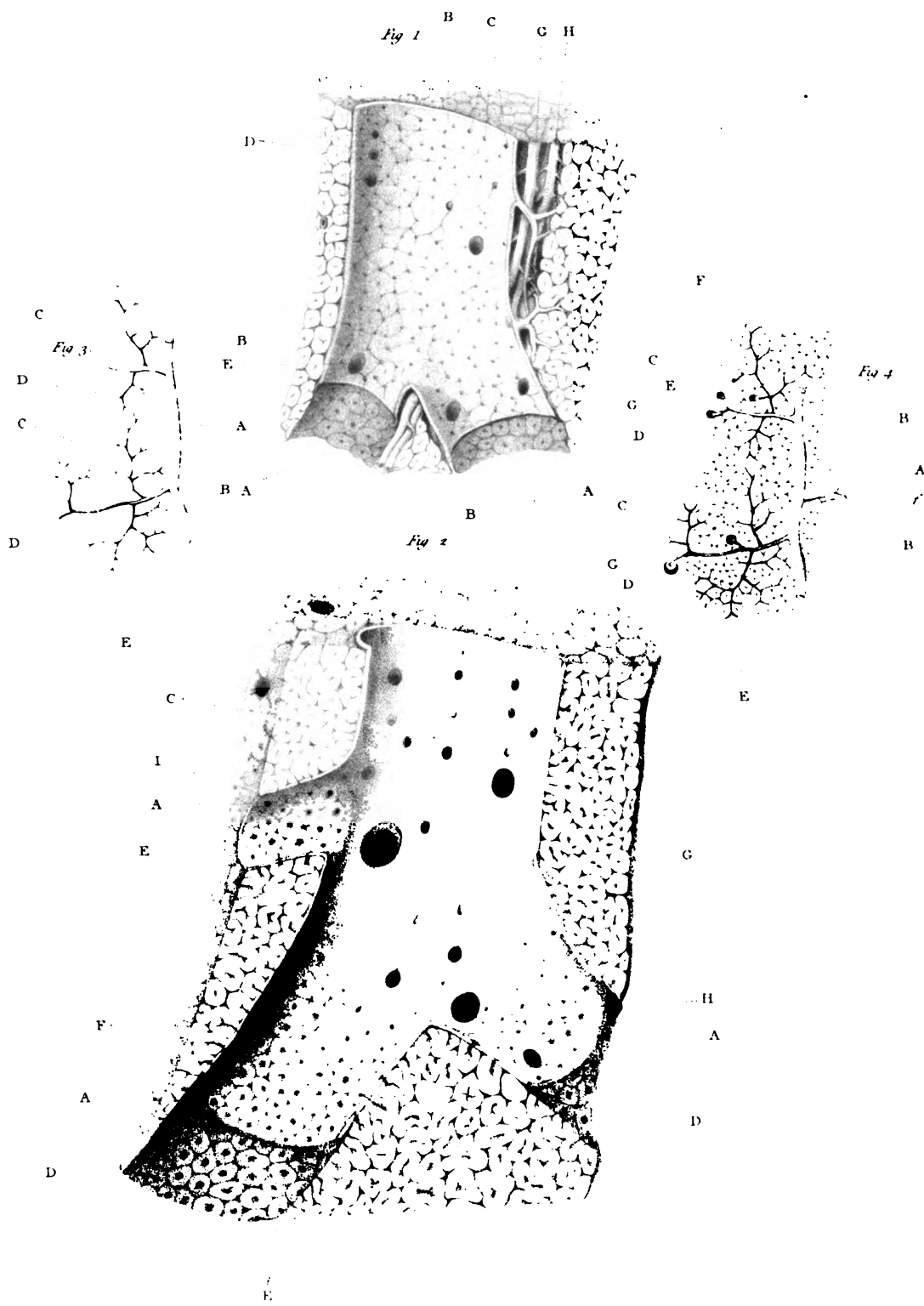
* These vessels, which are not mentioned by RUYSCH, HALLER, MORGAGNI, FERREIN, or by any other anatomist with whose works I am acquainted, did not escape the observation of MALPIGHI. "Ad singulos autem hosque minimos lobulos, prout experiri licet, et ex pluribus etiam colligere, multiplices vasorum rami derivantur; nam surculi venæ cavæ, et portæ, porique biliarii indeficenter per totum hepatis corpus ramificantur, ut luculenter etiam GLISSONIUS, in nondum satis laudato hepatis opere nobis indicat, et sanguineum vas in lobulis extimam hepatis superficiem constituentibus, à centro ejusdem erumpens, hinc inde ramificatur per totam periferiam bifidos promens ramos, à quo totus lobulus irrigatur."—De Hepate, cap. 2. And in his Opera Posthuma, p. 30, after speaking of the lobules, he says, "In horum centro scissura excitato sanguineo vasi extra erumpenti aditum præbet, quod in contiguas minimas glandulas, quibus lobuli quique integrantur, extremis finibus propagatur." It appears, however, that MALPIGHI mistook these branches of the hepatic vein for branches of the portal vein, and that he was acquainted with them in the superficial lobules only.

veins, would, in some places at least, be seen in contact, which is never the case.

The veins and fissures cannot be always seen without the aid of a magnifying glass; slight pressure, however, by which the blood is propelled into them, will generally make them visible. They may be always seen after a few hours maceration in water, or they may be shown by mercurial or size injections. For this purpose a liver containing the smallest quantity of blood should be chosen; and on this account the liver of the sheep is preferable to the human liver, the latter being generally in a state of congestion. The vena cava should be opened at its posterior part, and the mercury should be poured from a quill into the hepatic vein of the lobulus Spigelii. With slight pressure the mercury will appear in the centres of the lobules, in the form of lines, stellæ or points, surrounded by what has been called the red substance of the liver. If the liver contain much blood, the experiment may not succeed, for the blood will be propelled to the surface, and the vessels within the lobules will be no longer distinguishable from those between them. If the pressure be discontinued, the elasticity of the vessels will cause the mercury to retreat from the surface; if the pressure be renewed and slightly increased, the mercury will pass from the intralobular branches of the hepatic vein into the interlobular branches of the portal vein, and will be seen in the centre and at the circumference of every lobule. If the mercury be thrown into a branch of the portal vein, it will appear in the interlobular branches situated in the fissures and spaces. In the portal veins, which ramify in the cellulo-vascular capsules of the lobules, the mercury will have a dull appearance; it will be of its usual brilliancy in the intralobular veins, which, contained within the lobules, have no cellular tissue surrounding them.

Of the Portal Canals.—These canals commence at the transverse fissure, where they are continuous with the concave surface of the liver; they contain the hepatic ducts, the portal veins, the hepatic arteries, and the vaginal branches of all these vessels, with the nerves and absorbents, enveloped in a sheath of cellular tissue, first described by GLISSON, and called Glisson's Capsule*. If

* The right edge of the lesser omentum is usually called Glisson's Capsule in this country. GLISSON, after describing the suspensory ligament, says, "Ligamentum hoc non solum extimæ hepatis



a longitudinal section of one of these canals be made, and the contents be dissected out, lobules, spaces and fissures will be seen, arranged in a precisely similar manner to those already described on the external surface. The lobules forming the parietes of the canals are similar to those of the surface, being, like them, perforated by the intralobular veins: they may be called the portal canals or surfaces, the portal vein being the largest vessel contained in them. (Plate XXII. fig. 1, *a*.) These canals, and those containing the large hepatic trunks, are formed by the capsular surfaces of a limited number of lobules; the canals containing the sublobular-hepatic veins are formed by the bases of all the lobules.

Glisson's capsule has attracted much of the attention of anatomists. It was known to WALEUS* before it was described by GLISSON; to the latter anatomist, however, who has given a detailed account of it, it owes all its celebrity. He describes it as a prolongation of the suspensory ligament, which enters the liver for the purpose of supporting its weight†; he says it arises from the peritoneum, and is of a particular structure‡; he considers it as the muscular coat of the portal vein, by which the blood is propelled through the liver§. GLISSON supports his opinions respecting the structure and functions of the capsule with much ingenuity; they were admitted by MALPIGHI||, were, according to HALLER¶, strongly advocated by Pozzi, and generally adopted by anatomists until their fallacy was exposed by FANTON** and others. HALLER†† and SABATIER‡‡ considered the capsule as a prolongation of the cellular tissue

membranæ affigitur, sed etiam parenchyma ejus penetrat, et communi vaginæ sive involucro rami venæ portæ (quæ vena umbilicalis eidem continua est) validè adnectitur.—*Anatomia Hepatis*, cap. 2.

* “Imò in ipso hepate, tot rami arteriæ sunt, quot sunt rami venæ portæ, et totidem quoque sunt rami ductûs cholidochi. Quæ omnia hactenus ab anatomicis pro venis portæ habitæ sunt, quòd communi tunica tria illa vasorum genera in hepate includantur.”—JOS. WALEUS, *De Motu Chyli et Sanguinis*, ad T. BARTHOLINUM *Epistola Secunda*: 1640.

† *Op. cit.* cap. 2.

‡ *Ibid.* cap. 28.

§ *Ibid.* cap. 42.

|| *De Hepate*, cap. 2.

¶ “JOSEPHUS POZZI in *Commentariolo Epistolico pro glandulis hepatis, et Glissonianæ capsulæ carnis fibræ, pugnat.*”—*Methodus Studii Medici*, vol. i. p. 373.

** *Brevis Manuductio ad Historiam Anatomicam Corporis Humani*, p. 109: Taurini 1699.—*Dissertationes Anatomicæ*, p. 135: 1701. HALLER says, “G. COWPERUS, capsulam Glissonii primus, ni fallor, demonstravit parvi momenti esse.”—*Methodus Studii*.

†† “Nempe vena portarum multam cellulosam telam ex mesenterio et liene secum adfert.”—*Elementa Physiologiæ*, vol. vi. lib. 23.

‡‡ *Traité d'Anatomie*, tom. iii. p. 350.

which surrounds the vessels in the mesentery and lesser omentum. LAENNEC*, after describing the proper capsule of the liver, which had been previously described by SABATIER† and SCHEMERRING‡, the latter of whom calls it the *membrana cellulosa hepatis*, says, that this membrane, having covered the surfaces, enters the tissue of the liver, furnishing sheaths to all the vessels distributed to it, one of which, common to the vena portæ, biliary ducts and hepatic artery, constitutes Glisson's capsule. The capsule, he continues, is intimately connected with the substance of the liver, and is separated from the vessels by a loose and abundant cellular tissue, which is continuous with that surrounding the sinus of the vena portæ in the transverse fissure, and is connected with that of the mesentery; it is also continuous with that which connects the proper capsule with the peritoneum. LAENNEC is of opinion that Glisson's capsule allows the portal vein to yield and accommodate itself to the increased quantity of blood circulating through it during digestion. If it be true that more blood circulates through the liver during this period than at any other, which is denied by BICHAT§, yet LAENNEC's explanations of the function of the capsule cannot be admitted, for the hepatic veins would be equally subject with the portal vein to these variations in the circulation; the former vessels are, nevertheless, firmly connected to the substance of the liver, having no sheath of cellular tissue around them.

The cellular tissue of Glisson's capsule is undoubtedly continuous with that of the proper capsule of LAENNEC, and with the cellular tissue which surrounds the abdominal vena portæ, as described by HALLER and SABATIER; but, as M. Roux || observes, "il faut admettre quelque chose de plus dans ce qu'on nomme *capsule de Glisson*, puisqu'elle est tellement disposée que les vaisseaux qu'elle enveloppe sont lâchement unis à la substance du foie." Glisson's capsule is not mere cellular tissue: it is to the liver what the pia mater is to the brain; it is a cellulo-vascular membrane, in which the vessels divide and subdivide to an extreme degree of minuteness; which lines the portal canals, forming sheaths for the larger vessels contained in them, and a web in which the

* LAENNEC, Lettre sur des Tuniques qui enveloppent certains Viscères,—Journal de Médecine, par CORVISART, tom. v. p. 539.

† Traité d'Anatomie, tom. ii. p. 345: 1791.

§ Anatomie Générale, tom. ii. p. 248.

‡ De Corporis Humani Fabricâ, vol. vi. p. 168.

|| BICHAT, Anatomie Descriptive, tom. v. p. 98.

smaller vessels ramify; which enters the interlobular fissures, and, with the vessels, forms the capsules of the lobules; and which finally enters the lobules, and, with the blood-vessels, expands itself over the secreting biliary ducts. Hence arises a natural division of the capsule into three portions, a vaginal, an interlobular, and a lobular portion; and as the vessels ramify in the capsule, their branches admit of a similar division.

At the transverse fissure, the duct, vein and artery divide into branches, which enter the portal canals. These branches divide and subdivide into smaller branches, which enter smaller canals, and every canal, however small, contains one principal branch of each of these vessels; frequently, however, two ducts and two arteries are contained in the same canal. To these larger vessels the terms of hepatic ducts, portal veins and hepatic arteries may be confined, in order to distinguish them from the branches.

The excreting ducts are composed of the hepatic ducts, contained in the canals, of their vaginal branches, also contained in the canals, and of the interlobular branches, which, arising from the vaginal branches, ramify in the interlobular fissures. The interlobular ducts enter the lobules, in which they form plexuses. These plexuses may be called the lobular biliary, or secreting biliary plexuses, the ducts composing them being the secreting organs of the bile. The excreting ducts and their branches are invariably accompanied by the arteries and portal veins and their branches, the former conveying blood to their coats, the latter conveying it from them; a duct is never unaccompanied by an artery and vein, the vein being always a branch of the portal vein. The veins and arteries also enter the lobules. The veins form plexuses, the branches of which terminate in the intralobular hepatic veins; from the blood circulating through the plexuses, the bile is secreted. The lobular arteries are exceedingly minute, and few in number; they are the nutrient vessels of the lobules, and probably terminate in the plexuses formed by the portal vein. From the ducts, veins and arteries, therefore, three sets of branches arise, namely, the vaginal, the interlobular, and the lobular branches.

Of the Vaginal Portion of Glisson's Capsule and of its Vessels.—A branch of each vessel, contained in a portal canal, makes its exit from the canal at each interlobular space on its surface. The lobules being small bodies, the interlobular spaces are necessarily numerous and close together. The hepatic duct

and artery running together on one side of the canal, or winding spirally within it, are in apposition with but a very limited number of spaces; the two vessels are, however, brought into apposition with all the spaces by means of plexuses, from which the interlobular branches arise. (Plate XXI. fig. 5, *f. h.*) The portal vein also forms a plexus, being separated from the spaces by the duct and artery and their plexuses. (Plate XXI. fig. 5, *d.*) The branches forming these plexuses are the first which arise from the duct, artery and vein; they form a vascular sheath around these vessels, and may be called their vaginal branches; they ramify in a loose and fine cellular tissue, which, with them, constitutes the vaginal portion of Glisson's capsule. (Plate XXI. fig. 5, *j.*) This cellular tissue is continuous with that surrounding the vessels in the right edge of the lesser omentum, and with that of the proper capsule of LAENNEC. The internal surface of the cellulo-vascular sheath is in contact with the three principal vessels, and is composed of the largest branches arising from them. Its external surface is in contact with the parietes of the canal, and is composed of the smallest branches; these branches form a reticulated plexus, from which the interlobular branches shoot out, and entering every interlobular space, ramify between the lobules. (Plate XXI. fig. 5, *i.*) In the smaller canals, the fissures and spaces being less numerous, and the plexuses formed by the duct and artery being consequently less complicated, a great portion of the portal vein is in contact with the parietes of the canal. In these canals many of the interlobular veins arise immediately from the trunks, vaginal branches being given off, and forming a plexus, on that side only of the canal occupied by the duct and artery. In these canals we find the capsule, the essential part of which is the plexus, only on that side which is occupied by the duct and artery, the vein being in contact on the opposite side with the parietes of the canal. In the larger canals, in which the lobules and spaces are more numerous, and the plexuses necessarily more complicated, the sheath completely surrounds the three vessels. These two modes of arrangement of the capsule may be ascertained by making transverse sections of canals of different calibre. In a small canal in which the capsule is found only on that side occupied by the duct and artery, the portal vein should be laid open, and its internal surface examined. The fissures and lobules will be seen through the transparent coats of the vein on that side on which there is no capsule, and on the internal

surface of the vein numerous minute orifices will be observed, corresponding exactly to the interlobular spaces. These orifices are the mouths of interlobular veins, which enter the spaces without contributing to the formation of the plexus. (Plate XXI. fig. 6, *b*. Plate XXII. fig. 1, *c*.) A few larger orifices, not corresponding to the spaces, will also be seen: these are the mouths of vaginal branches, which divide in the canal into two, three, or more interlobular branches, and thus contribute partially to form the plexus. (Plate XXII. fig. 1, *d*.) On that side of the vein which is in contact with the artery and duct, and separated by them from the spaces, the orifices are larger and less numerous; these are the mouths of vaginal branches, which, ramifying in the canal, terminate in interlobular branches, which enter those spaces covered by the duct and artery. (Plate XXI. fig. 6, *c*. Plate XXII. fig. 1, *f*.)

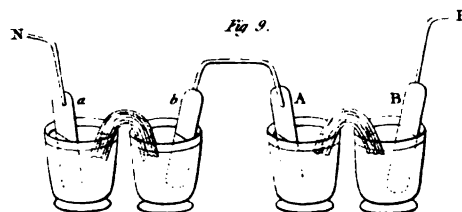
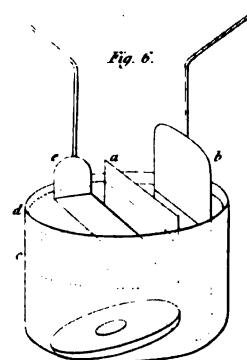
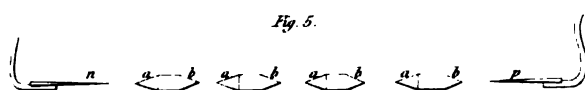
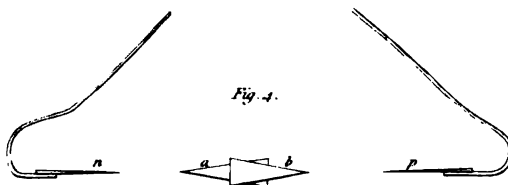
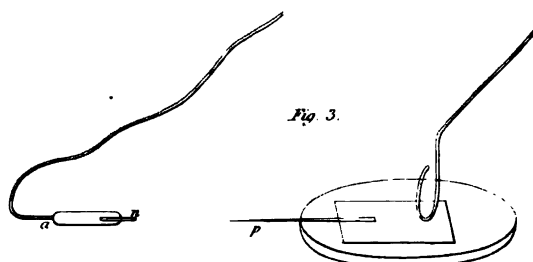
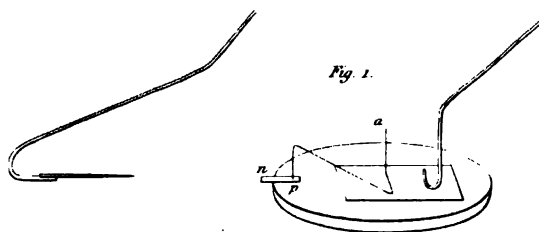
From the above description it is evident that Glisson's capsule is a cellulovascular membrane, composed of the vaginal branches of the duct, vein and artery, ramifying in a layer of cellular tissue. Its existence around the three vessels in the larger canals, in which the vaginal plexus is most complicated; its existence on that side only of the smaller canals occupied by the duct and artery, and its almost total absence on the opposite side, sufficiently prove that by its means the three vessels are brought into apposition with all the interlobular spaces on the surfaces of the canals. The vaginal vessels are best seen by making longitudinal sections of canals, and dissecting out the three large vessels after having injected them. The mouths of the interlobular branches arising from the smaller portal veins may be shown by opening a vessel and removing the injection carefully from the trunk, leaving it in the branches. The internal surfaces of the ducts and arteries exhibit no orifices of interlobular branches, these branches always arising from the plexus which each duct and artery, however small, forms in the canal in which it is contained. The portal vein, like other vessels, occasionally varies in the manner in which it gives off its branches; thus, even in the smallest canals, it frequently happens that the three vessels are surrounded by the capsule. In this case the vein gives off vaginal branches only, and no interlobular branches, all the latter arising from the former.

The first vaginal branches of the ducts arise at nearly right angles with the trunks; they run in a transverse direction within the inner surface of the canal,

and terminate in branches which correspond to, and lie on, the fissures. Each transverse branch gives off one or two branches which ramify in the direction of the trunk, and one or two recurrent branches. All these branches run in the direction of the fissures, forming angles at the spaces over which they pass. At each angle a smaller branch is given off, which runs on a fissure leading from the space over which the angle in the vessel is formed. Thus, if the vessels be well injected, all the fissures and spaces will be covered by small ducts, which form a network of vessels corresponding in form to the fissures on which they lie. The transverse branches, and those which arise immediately from them, do not anastomose with each other, but the smaller branches sometimes appear to do so; I cannot, however, from dissection, affirm that they do, for those which appear to anastomose are exceedingly small vessels, and meet each other at the spaces; hence it is difficult to ascertain whether they really anastomose, or enter the spaces together without anastomosing. From the vaginal ducts spread over the surface of the canal, lobular and interlobular ducts arise; the former enter the lobules on the parietes of the canals; the latter leave the canals at the spaces to ramify between the lobules, which they finally enter. (Plate XXII. figg. 3. and 4.) The vaginal ducts are sometimes very tortuous in their course.

The coats of the ducts are highly vascular; the rugæ on their internal surface, and those on the internal surface of the gall-bladder, are formed by the ramifications of the larger blood-vessels, arteries as well as veins, covered by the mucous membrane. This membrane is studded with vascular papillæ, which become remarkably developed in the diseased ducts so frequently found in sheep and oxen. The smaller ducts are furnished with papillæ only, and to the rupture of the delicate vessels forming these papillæ is to be attributed the facility with which SÆMMERRING and other anatomists injected the ducts from the arteries and veins, and not to any direct communication between the vessels and the ducts. This point has been particularly insisted upon by MÜLLER, who, in speaking of WALTER's experiments, says, "*Itaque si in WALTERI experimentis massa interdum ex vasis sanguiferis in ductum hepaticum transiit, certe non per minimos ductus biliferos transiit, sed in truncos ipsos ex vasculis sanguiferis erupit*.*" MAPPE imagines that the hepatic artery is principally destined to

* Op. cit., p. 83.



supply the coats of the portal vein with blood: this is so far from being the case, that when the arteries are well injected, the larger ducts, from the extreme vascularity of their coats, may be mistaken for the injected arteries, whilst, in the coats of the vein, no vessels will be detected without the aid of the magnifying glass*. The coats of the ducts may be as highly injected from the portal vein as from the hepatic artery; but they cannot be injected from the hepatic veins, if the injection is confined to these vessels, and does not return by the portal vein. MAPPES could not inject the ducts from the portal or hepatic vein; he is nevertheless of opinion, "*que la bile est tirée plutôt du sang déjà parvenu dans cette veine (la veine hépatique) que de celui qui se trouve encore dans les dernières extrémités de la veine porte.*" The ducts cannot be injected in a direct manner from the hepatic vein, no branches of this vein ramifying in their coats; fluid may indeed be made to pass from this vein into the ducts, but only through the medium of those branches of the portal vein which ramify in the coats of the ducts†. The ducts are injected from the portal vein and from the hepatic artery in the same manner as the foetal intestine is frequently filled with injection from the umbilical vein or aorta, viz. by the rupture of the minute vessels of the mucous membrane. Hence it is evident that the ducts, so far as they have been yet traced, are abundantly supplied with arterial blood; that this blood returns into the branches of the portal, and not into those of the hepatic veins; and that the hepatic portal vein has branches of origin in the coats of the excreting ducts from the terminations of the hepatic artery, as the abdominal portal vein arises in the coats of the intestines, in the spleen and pancreas, from the arteries of these organs.

From their extreme vascularity alone we might infer, that the ducts serve

* MAPPES probably saw the vaginal arteries, which ramify on the parietes of the canal previously to entering the interlobular spaces, through the transparent coats of the veins, and concluded that they were ramifying in the coats of these vessels; or in making sections, this anatomist may have removed a portion of the parietes of a canal, leaving the arteries on the vein.

† By examining the surface of the liver after injecting the hepatic veins, we may ascertain in which parts the coats of the ducts are injected from these vessels, and in which they are not. If on one portion of the surface we see the interlobular portal veins injected from the hepatic veins, a few injected vessels will be found in the coats of the ducts of this part. In other parts of the liver, where the injection is confined to the centres of the lobules, and consequently to the hepatic veins, no injection will be found in the coats of the ducts, although the injected hepatic veins will be seen through them.

another purpose beside that of the conveyance of bile; and all anatomists are acquainted with the muciparous follicles of the lining membrane of their larger branches; in the smaller branches, the existence of the follicles has been denied*. In the former, they are irregularly distributed over the surface; in the latter, they are closely arranged in two longitudinal lines, occupying opposite sides of the ducts; and, arranged in this manner, they will be found in the smallest duct that can be examined. MAPPEs confounded the follicles with the orifices of vessels. Their number renders it probable that the fluid furnished by them serves another purpose beside that of rubricating the surfaces of the ducts†. Some estimate of the quantity of this fluid may be formed by examining the ducts, after having injected them with alcohol. These follicles are probably the secreting organs of all the mucus found in the bile. (Plate XXIII. fig. 1.)

The vaginal ducts are accompanied by the vaginal arteries; the latter, however, are more or less tortuous in their course, the former generally proceeding in the shortest direction to their destination. The vaginal arteries anastomose freely with each other, but their ramifications do not, like those of the ducts, correspond exactly to the fissures. If the left artery be injected in the transverse fissure, the injection will return by the right artery; this communication takes place by means of vaginal branches which the left artery gives off in the fissure, and which anastomose with similar branches of the right artery.

The vaginal branches of the vein anastomose with each other; they form a much more complicated plexus in the human liver than in the liver of most animals, and on this account the cellular tissue of Glisson's capsule is more abundant in the former, and greater difficulty is experienced in examining the plexuses formed by the ducts and arteries. In the sheep, portal veins of considerable size resemble the smaller portal veins in the human subject, vaginal branches arising from them on that side only of the canal occupied by the duct and artery, and interlobular branches on the other side. On this side,

* MECKEL, *Op. cit.*, tom. iii. p. 455.

† The internal surface of the pancreatic duct is studded with follicles similar to those of the hepatic ducts; they assume no particular arrangement. They are numerous and very apparent in some subjects; in others I have found no trace of them. The parotid and submaxillary ducts are not furnished with follicles.

Fig. 1



Fig. 2

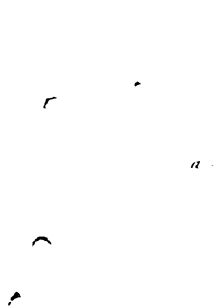


Fig. 3

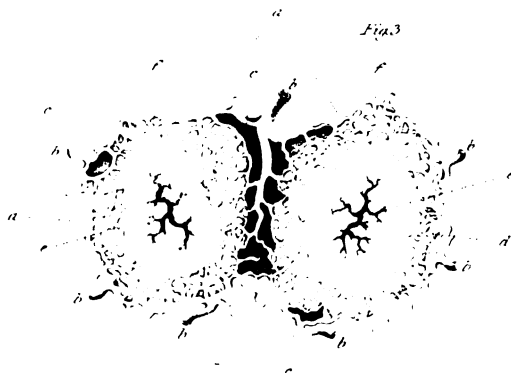


Fig. 4



Fig. 5

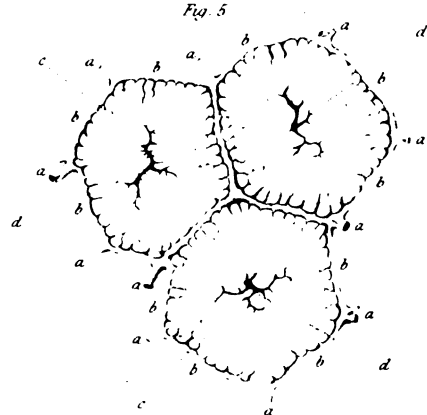
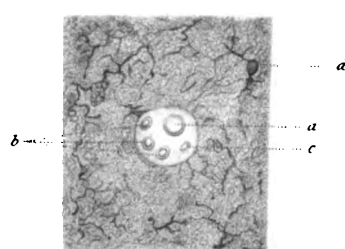


Fig. 6



therefore, we find the cellular tissue in small quantity, no venous plexus being formed, and the injected vaginal ducts and arteries may be seen without dissection through the transparent coats of the vein.

The nerves and deep-seated absorbents ramify in the portal canals ; I have not been able to trace them into the interlobular fissures. The absorbents may be always injected from the duct, and the bile is frequently propelled into the former vessels by injecting the latter. MASCAGNI * found that injection thrown into the ducts returned colourless by the absorbents. I have frequently made the same observation, but I have as frequently found the injection in the absorbents of the same colour as that thrown into the duct, and have frequently filled all the absorbents of the right edge of the lesser omentum with red size from the duct. In one instance, and in the only one in which the trial was made, the thoracic duct was injected with mercury from the hepatic duct. LIPPI asserts that "the lymphatics terminate not only, as has been hitherto supposed, in the thoracic duct and in the right subclavian vein, but that an infinite number of communications exist between the veins and lymphatics in other parts of the body†." AN TOMMARCHI‡ asserts that no such communications take place ; and LIPPI's opinions appear to have been satisfactorily refuted by PANIZZA §. No absorbents accompany the hepatic veins, and it is not probable that any of the absorbents of the liver terminate in the branches of the portal vein, the fluids in these two systems of vessels proceeding in different directions. The superficial absorbents ramify in the proper capsule. After injecting these vessels, the peritoneal coat may be removed without injuring them ; or the peritoneal coat may be first removed, and the absorbents afterwards injected ; and some few may be injected in the proper capsule after the separate removal of both. This can be done in the human subject and in the larger animals only, the proper capsule being of a much more delicate structure, or probably not existing, in the smaller animals, in which the liver appears to have no superficial absorbents. Injection sometimes passes from the arteries and portal veins into the absorbents.

Of the Interlobular Portion of Glisson's Capsule and of its Vessels.—As the interlobular ducts, veins and arteries arise from the vaginal ducts, veins and

* Prodomo della Grande Anatomia, p. 141.

† Illustrazioni del Sistema linfatico-chilifero, p. 10.

‡ Journal Hebdomadaire, tom. iv. p. 214.

§ Annali Universali di Medicina, vol. lvi. p. 225.

arteries, so the interlobular cellular tissue is continuous with the vaginal cellular tissue, the vessels and cellular tissue together constituting the interlobular portion of Glisson's capsule, which occupies the fissures and forms the capsules of the lobules *. The interlobular vessels, at their origin from the vaginal vessels, enter the spaces; in the spaces, therefore, we find the largest branches; these divide into smaller branches, which ramify in the fissures.

If the left hepatic duct be injected with size or mercury, the injection will return by the right duct, without extravasation and without passing into other vessels, and the injection will be found in the interlobular and vaginal ducts as well as in the trunks. This communication between the two ducts does not take place, like that which exists between the right and left arteries, through the medium of the vaginal branches of the transverse fissure, the injection being found in interlobular branches arising from the right duct. From this experiment, which I have frequently repeated with the same result, it appears that the right and left duct anastomose with each other through the medium of the interlobular ducts. This experiment does not always succeed, which probably arises from the quantity of bile contained in the ducts.

The interlobular branches of the portal vein cover, with their ramifications, the whole external surfaces of the lobules, with the exception of the bases of these bodies, and of those extremities of the superficial lobules which appear on the surfaces of the liver. The freest communications take place between these vessels; when successfully injected, which can be done with size only, the interlobular fissures in which they are contained, whether examined on the surfaces of the liver, or on the surface of a section, are coloured with the injection. Mercury thrown into a large branch of the portal vein returns by other large branches. This communication takes place through the medium of the interlobular branches, for though the vaginal branches in the same canal anastomose freely with each other, yet those of one canal communicate with those of another through the medium of the intervening interlobular branches alone. The interlobular veins also form communications between the lobular

* The interlobular portion of Glisson's capsule is thus accurately described by MALPIGHI: "*Lobuli hi propriâ circumambiente membranâ vestiuntur, et continuatis per transversum membranis nexibus firmanur, ita ut intermedia spatia, et rimulæ, minimæ tamen, inter lobulorum latera emergant.*" —*De Hepate*, cap. 2.

veins of a lobule, and those of the contiguous lobules. Hence it appears, contrary to the assertions of BICHAT* and MAPPES†, that the freest anastomoses exist between all the branches of the portal vein, and that the interlobular branches form the medium of communication.

When the portal vein is imperfectly injected, and the venous circles, formed by its interlobular branches around the lobules, are not brought into view, these branches are seen in the spaces, and three or four smaller branches are seen shooting into the fissures communicating with the spaces. These are the stellated vessels of anatomists. When the vessels are well injected, the stellæ are all continuous with each other, and the venous circles are formed; the stellated appearance, therefore, arises from the incomplete injection of the vessels. If the liver do not contain much blood, stellæ may be always produced on its surface by pressure.

No anastomoses can be shown to exist between the interlobular arteries, these vessels, even when most successfully injected, appearing like points, lines and stellæ in the fissures and spaces. The right artery may be injected from the left in the transverse fissure, and it has been shown that this communication takes place by means of the vaginal branches given off by the two arteries in the fissure; but if the left artery, or a branch of it, be injected at its entrance into its canal, after the vaginal branches of the fissure are given off, the injection will not return by the right artery. From this experiment it would appear that no anastomoses take place between the interlobular arteries; but as the vaginal arteries communicate freely with each other, and as the interlobular ducts also communicate with each other, and as the arteries ramify in the coats of the ducts, we may conclude that the interlobular arteries anastomose.

From the superficial interlobular fissures, small arteries emerge and ramify in the proper capsule on the convex and concave surfaces of the liver, and in the ligaments. These are the capsular arteries. They vary much in number in different subjects, being always most numerous in those in which the capsule is most developed. In those animals in which the liver has a peritoneal

* Speaking of the anastomoses of the portal vein, BICHAT says, "Sa portion hépatique paraît en manquer: toutes les branches, rameaux et ramuscules, marchent isolément."—*Anatomie Générale*, tom. ii. p. 247.

† Loc. cit.

coat only, and no proper capsule, no capsular arteries can be shown by injection. In those subjects in which the capsular arteries are numerous, these vessels cover the surfaces of the liver with a beautiful plexus: those of the right lobe anastomose with those of the left, and both anastomose with branches of the phrenic, internal mammary and supra-renal arteries; some, leaving the liver, ramify under the peritoneum covering the right kidney; others pass along the ligamentum teres to the umbilicus, and anastomose with the epigastric arteries.

WALTER did not distinguish the proper capsule, described by SÆMMERRING and LAENNEC, from the peritoneal coat of the liver, the latter of which, he says, has no vascular connexions with the liver, but receives vessels from the vessels of the peritoneum, which, according to this anatomist, are branches of the internal mammary, epigastric, phrenic, intercostal and lumbar arteries. In his most successful injections of the vessels of the liver, WALTER could detect no vessels in the peritoneal coat "*nec nudo nec armato oculo, sed apparuit hæc membrana ut in hepatibus non injectis, alba neque vasis picta* *." WALTER erroneously concludes that this membrane has proper vessels, arising from the sources above enumerated, and having no connexion with those of the liver. All the capsular arteries, arising from whatever source, ramify in the proper capsule, and they may be all injected from the hepatic artery. I have never seen injected vessels in the peritoneum, but as recent adhesions between the liver and diaphragm may be injected from the hepatic artery, it appears evident that the peritoneal coat of the liver is nourished by this artery. That the proper vessels of the liver anastomose with those which WALTER calls the proper vessels of the membrane, is proved by the fact, that recent adhesions between the right lung and the diaphragm may be injected from the hepatic artery, the injection passing from the capsular branches of this vessel into those of the phrenic, and thence into the phrenic arteries themselves †. The capsular veins are branches of the portal vein; these vessels communicate freely with branches of the phrenic veins. In some cases of atrophy of the liver, and in cases in which the circulation through the liver has been for some time obstructed, a

* De Hepate, p. 88.

† The capsular arteries have been well delineated by RUYSCH, *Thesaurus Anatomicus Decimus*, No. 181. tab. 3. fig. 5.

collateral circulation is established by means of the communications which take place between the capsular branches of the hepatic artery and portal vein and those of the phrenic artery and vein.

All the *vasa vasorum* of the liver are branches of the hepatic artery and portal vein. Branches of the artery ramify in the coats of the duct, artery and portal vein; veins arise in the coats of all these vessels, and terminate in branches of the portal vein. In the hepatic-venous canals, and in the fissure of the inferior cava, small arteries issue from the interlobular fissures, and ramify in the coats of the hepatic veins and inferior cava; veins arise in the coats of these vessels, and entering the interlobular fissures, terminate in branches of the portal vein. All the veins arising in the coats of the vessels, and terminating in the portal vein, constitute the hepatic origin of this vein.

The trunks of the duct, vein and artery in each canal, terminate in interlobular branches. Vaginal vessels, giving off interlobular vessels, ramify in the transverse fissure, in the fissure of the gall-bladder, and in that containing the obliterated umbilical vein and ductus venosus; these fissures, therefore, must be considered as portions of portal canals.

Of the Hepatic Veins, and of the Hepatic-venous Canals.—The hepatic veins are contained in canals, which may be called the hepatic-venous canals; they commence in the interior of the liver, and terminate at the fissure of the inferior cava. Those containing the hepatic trunks are formed by the capsular surfaces of a limited number of lobules; those containing the sublobular-hepatic veins, are formed by the basis of all the lobules.

As three vessels are contained in each portal canal, and as a branch of each vessel makes its exit from the canal at each interlobular space, each vessel necessarily forms a plexus, by which it is brought into apposition with all the spaces on the surface of the canal: but one vessel only, an hepatic vein, being contained in each hepatic-venous canal, the external surface of the vein is in contact with, and connected to, all the lobules forming the parietes of the canal, the intralobular veins, at their exit from the lobules, entering the sublobular-hepatic veins without uniting in the canals to form branches similar to the vaginal branches of the portal vein, duct and artery. The interlobular branches of the vein and artery conveying blood to the lobules, correspond to the intralobular branches of the hepatic veins, which convey the blood from

the lobules; the former arise from the vaginal branches, the latter terminate in the sublobular-hepatic veins. Thus we find that the hepatic veins have no branches corresponding to the vaginal branches of the duct, portal vein and artery; and as Glisson's capsule is composed of the vaginal vessels ramifying in cellular tissue, we consequently find nothing similar to this capsule around the hepatic veins, these veins having no vaginal branches. In the smaller portal canals, in which the spaces are less numerous and the plexus less complicated, one side of the portal vein is in contact with the parietes of the canal. On this side the interlobular branches arise immediately from the vein, and the cellular tissue is in small quantity, forming a delicate membrane on the walls of the canal; on the opposite side, which is separated from the walls by the duct and artery, vaginal branches arise from the vein, and the cellular tissue is abundant. (Plate XXI. fig. 6.) These smaller portal veins resemble the hepatic veins on that side on which they are in contact with the walls of the canal, on which no vaginal branches are given off, on which the interlobular branches arise immediately from them, and on which there is no capsule; they resemble the larger portal veins on that side on which vaginal branches arise from them, and on which the capsule consequently exists. From the absence of vaginal branches on one side of these portal veins, it may be presumed, that should a portal vein be found entering the liver unaccompanied by a duct and artery, it would, like the hepatic veins, be connected to the parietes of its canal, and would, like these vessels, have no vaginal branches, and, consequently, no capsule. The structure and uses of Glisson's capsule are now fully explained, it being evident that the loose connexion of the ducts, portal veins, and hepatic arteries to the substance of the liver arises from the circumstance of the three vessels ramifying in the same canals; and that the adhesion of the hepatic veins to the substance depends on one vessel only being contained in each hepatic-venous canal.

Numerous minute orifices are seen on the internal surface of the sublobular-hepatic veins; these orifices are the mouths of the intralobular veins, all of which terminate immediately in these vessels*. Every orifice corresponds to

* The orifices of the intralobular veins are most distinctly shown by injecting the hepatic veins with coloured size, by then making longitudinal sections of the veins and removing the injection from them, leaving it in the intralobular branches.

the centre of the base of a lobule ; the number of orifices is therefore equal to the number of lobules forming the parietes of the canal in which the vein is contained. (Plate XXII. fig. 2, *e*.) As an intralobular vein makes its exit from the base of every lobule, and as every intralobular vein terminates in a sublobular vein, it is evident that the base of every lobule is in contact with a sublobular vein, and that the hepatic-venous canals containing these vessels are formed by the bases of all the lobules of the liver. The parietes of the portal canals are also composed of lobules ; but they are composed of the capsular surfaces of lobules, and not of the bases, nor do all the lobules enter into their formation as into that of the hepatic-venous canals ; for, as the interlobular ducts, veins and arteries ramify in fissures continuous with each other throughout the liver, many of these vessels terminate in lobules situated at a distance from the trunks from which they arise, these distant lobules not contributing to form the canals containing the trunks. As all the lobules unite to form the hepatic-venous canals, and as a certain number only enter into the formation of the portal canals, it is evident that the former are more numerous than the latter.

In the description of the lobules, the hepatic veins contained in canals were divided into two sets, into the sublobular-hepatic veins, and the hepatic trunks. The coats of the former are delicate in texture ; they are transparent ; the lobules and fissures are seen through them ; their internal surface is studded with the orifices of intralobular veins ; their canals, which are formed by the bases only of lobules, are not lined by prolongations of the proper capsule. (Plate XX. fig. 2, *b*. Plate XXII. fig. 2, *a*.) The trunks are more dense in structure ; their external coat is composed of longitudinal bands ; their canals are lined by prolongations of the proper capsule, which render them opaque, the lobules and fissures not appearing through them ; they receive no intralobular branches. Dense in structure, they are not adapted to receive these minute and delicate veins ; their canals, therefore, unlike those containing the sublobular veins, are, like those containing the portal veins, composed of the capsular surfaces of lobules, the intralobular veins of which terminate in a neighbouring sublobular vein. (Plate XX. fig. 2, *c*. Plate XXII. fig. 2, *b*, *c*.)

If the internal surface of the large veins, which open into the trunks, be examined, and contrasted with the internal surface of a sublobular vein, the

orifices of the intralobular veins will be found less closely arranged in the former than in the latter. (Plate XXII. fig. 2, *g. h.*) This appearance arises from two causes. Two or three intralobular veins at their exit from the lobules, frequently unite and form one vein, which terminates in the large vein, on the internal surface of which will be seen one larger orifice, instead of three smaller orifices. Frequently also on the surfaces of these canals the capsular surfaces of lobules are seen, the bases of which enter into the formation of a neighbouring canal; no orifices, therefore, corresponding to the bases of these lobules are found in the veins under examination.

The intralobular veins will almost invariably be found entering the sublobular veins from the centre of what has been called the red substance of the liver. (Plate XXII. fig. 2, *e.*)

Of the formation of the hepatic-venous canals it may be said, that the smallest of the canals, and the greater number of them, are formed by the bases alone of lobules; that the next in dimensions are formed by the bases of some, and the capsular surfaces of other lobules; and that the largest are formed by the capsular surfaces only of these bodies. As the base of every lobule rests on a sublobular-hepatic vein, it is evident that those lobules, the capsular surfaces of which enter into the formation of canals, are in contact with two hepatic veins.

Ramifying in fissures which are continuous with each other throughout the whole liver, the interlobular branches of the portal vein anastomose freely with each other, enveloping every lobule in a venous web: the intralobular branches of the hepatic veins, on the contrary, confined within the lobules, have no direct communication with the corresponding branches of the surrounding lobules, from which they are separated by the substance of these bodies, and by the intervening interlobular ducts, veins and arteries, situated in the interlobular fissures; and one intralobular vein can be injected from another only through the medium of the intervening portal veins. When injected with mercury or size, the intralobular veins appear in the centres of the lobules in the form of points, stellæ, or twigs; these veins, therefore, unlike the interlobular portal veins, do not anastomose with each other. If, by means of a pipe and glass tube, mercury be thrown into a large hepatic vein on the surface of a section, it will return by several smaller neighbouring hepatic veins, which, generally, are

branches descending to terminate in the larger vessel in which the pipe is fixed. If these vessels be tied, the mercury will return by large hepatic veins, situated at a distance from the injected vessel, and not branches of it. In this experiment the force used is not sufficient to propel the mercury through the intervening intralobular, lobular and interlobular veins, and by such means to form a communication between the two hepatic veins; for if force sufficient to effect this were used, the mercury would return by portal as well as by hepatic veins, which is not the case. If the inferior cava be opened at its posterior part, and if by the same means mercury be thrown into a small hepatic vein, it will immediately return to the cava by other hepatic veins, without appearing in the superficial intralobular veins, and without passing into portal veins. From these experiments it appears that the sublobular veins anastomose with each other, and that their intralobular branches do not*.

By contrasting the hepatic veins with the portal vein, we find that no two intralobular branches of the former anastomose with each other; that the interlobular branches of the latter form one continuous plexus throughout the whole liver; that the sublobular veins anastomose directly, and not through the medium of the intralobular branches; that the portal veins have no direct communication with each other, but anastomose by means of their interlobular branches; that the hepatic veins, like the other veins of the body, proceed in a direct course to their termination in the cava; that the portal vein, accompanied by an artery, resembles an artery in its ramifications; that the larger hepatic veins, having longitudinal fibres in their coats, differ in structure from the portal vein; and that the blood contained in the liver after death is almost invariably found in the hepatic veins, the portal vein being usually empty.

The longitudinal fibres in the coat of the larger hepatic veins are similar to those in the coats of the iliacs and inferior cava, and to those which are occasionally seen in some superficial veins. Those of the iliacs and cava have been delineated by SENAC†, who says they are composed of muscular fibres. This

* The most superficial vessel, the intralobular branches of which are seen on the surface, should be chosen for these experiments, and in order to ascertain that the mercury does not pass into the portal vein, a section of the liver should be made at some distance below the injected vessel. A glass tube and pipe, whereby the pressure may be graduated, should be always used in these experiments. Size injected into one hepatic vein will always, and wax will sometimes, return by other hepatic veins.

† *Traité de la Structure du Cœur*, tom. i. p. 254. Pl. IV. fig. 3.

opinion, which was adopted by PORTAL*, is sufficiently refuted by the existence of similar fibres in the hepatic veins, which, being firmly connected to the substance of the liver, admit of no motion.

The hepatic veins in the *Seal* differ in many respects from those of any other animal I have examined. The intralobular veins at their exit from the lobules do not, as in other animals, terminate immediately in the hepatic veins: these vessels enter the hepatic-venous canals, where they unite into branches, which, like the vaginal branches of the portal vein, are connected by a fine cellular tissue, with which they form around the hepatic veins a cellulo-vascular sheath, precisely similar to that surrounding the branches of the portal vein. The structure of the two sheaths is similar, but their uses are different. That of Glisson's capsule has been explained; the capsule of the hepatic veins in the seal appears destined to admit of the muscular contractions of these vessels. The posterior cava in this animal forms at the back part of the liver a large sinus in which the hepatic veins terminate, and which, according to CUVIER, "is connected with the power of diving, which these animals possess in a high degree†." The external coat of the hepatic veins is composed of circular fibres, which in the larger vessels form a complete tunic. In the smaller vessels the fibres are arranged in the form of circular fasciculi, which are connected with each other by oblique intermediate fibres. All the fasciculi do not extend completely round the veins; some, dividing into two portions, unite with fibres from those above and below, and form other fasciculi. (Plate XXIII. fig. 2.) By contrasting the hepatic veins in the seal with those in the human subject, it would appear that the circular bands in the former are composed of muscular fibres. In man, the fibres are longitudinal; in the seal, they are circular: in the former, the vessels adhere firmly to the parietes of their canals; in the latter, they are loosely connected by the cellulo-vascular sheath in which they are inclosed. The existence of the sinus in which these veins terminate, and in which the blood accumulates during the act of diving, appears to indicate the necessity of a muscular power to propel the blood onward to the heart. Had the intralobular veins in the seal terminated, as in other animals, immediately in the hepatic veins, these vessels would have been connected to every lobule forming the parietes of their canals, and their muscular contractions could not

* Anatomie Médicale, tom. iii. p. 348.

† Leçons d'Anatomie Comparée, tom. iv. p. 265.

have taken place; the use of their sheaths is therefore evident, and different from that of the portal vein, hepatic duct and hepatic artery. No circular fibres exist in the coats of any of the other veins of this animal.

In the *Porpoise* the hepatic veins are connected to their canals; no circular fibres are seen in their coats. Their external surface is reticulated, the ridges corresponding to the interlobular fissures, where the interlobular cellular tissue is continuous with the cellular coat of the veins. The mouth of an intralobular vein occupies the centre of each space circumscribed by the ridges.

In diving birds, CUVIER says*, "all that portion of the vena cava inclosed in the liver is of very considerable diameter, and forms a kind of reservoir similar to that in the seal." I have examined some birds of this class, but have found no circular fibres in their hepatic veins.

Of the Structure of the Lobules.—The lobules constitute the secreting portion of the liver. Examined with the microscope, a lobule is apparently composed of numerous minute bodies, of a yellowish colour (imparted to them by the bile they contain) and of various forms, connected with each other by vessels. These minute bodies are the *acini* of MALPIGHI; his opinions respecting their structure and use are well known. RUYSCH† admitted the existence of the acini, and, more successful in his injections than MALPIGHI, he filled the minute vessels which are described by the latter anatomist as ramifying between these bodies; he thereby, probably, rendered the acini invisible, or less apparent than they present themselves in the natural state, in which they had been discovered by MALPIGHI, and he concluded that these minute bodies are composed of the terminal extremities of the vessels, with a certain number of which the ducts are continuous. BOERHAAVE‡ attempted to reconcile the contending opinions of the two great anatomists. FERREIN§ successfully opposed these opinions; he demonstrated the tubular structure of the kidney, and was the first who asserted that several other viscera, the liver, spleen and renal capsules, "sont un assemblage merveilleux de tuyaux blancs, cylindriques différemment repliés." MASCAGNI|| says the liver is composed of cells, from which the minute biliary ducts arise, and this anatomist enters into a description of

* Op. cit., tom. iv. p. 274.

† Epistola Anatomica ad F. RUYSCH.

|| Prodomo, p. 142.

† Epistola Anatomica ad H. BOERHAAVE.

§ Mémoires de l'Académie Royale des Sciences, 1749.

the various tunics of which these supposed cells are composed. To MÜLLER, whose recent discoveries have thrown much light on the ultimate structure of glands, is due all the merit of the important discovery, that a gland is a duct, with blood-vessels ramifying on its parietes. This anatomist asserts, from analogy rather than from actual demonstration, that the biliary ducts in the vertebrated, like those in some of the invertebrated animals, terminate in cæcal extremities, which present certain differences in the manner of their arrangement in the different classes. The foliated and pinnate appearances delineated in MÜLLER's 11th plate, and displaying, according to this anatomist, the manner in which the terminal extremities of the ducts are arranged, appear to me to result solely from partial congestion of the liver, the foliated portions being composed of the non-congested opposed edges of lobules, with the interlobular ducts, veins and arteries ramifying between them*. This state of the organ I have represented in Plate XXI. fig. 3. Appearances somewhat similar to those represented by MÜLLER, Tab. XI. fig. 11, have been delineated by Dr. HOPE in his valuable work on Morbid Anatomy. In describing figg. 104 and 105, Dr. HOPE says†, "The acini or white substance of the liver displayed with singular and unusual distinctness: from a case in which the vena portæ was plugged with coagula and fibrinous concretions. The acini were very small, pale and collapsed, as if they had lost a portion of their supply of blood, thus allowing the red substance which occupied a preternatural space to encroach upon and compress them." The small bodies represented in these figures are composed of non-congested portions of three contiguous lobules, "the small puncta or depressions in the centre" being interlobular spaces, containing branches of the duct, portal vein and artery. These bodies being neither acini nor lobules, and the branches of the portal vein here represented being situated between, and not in, lobules, it cannot, from these appearances at least, be inferred, as Dr. HOPE inquires, "that the principal part of the portal blood is distributed to the acini." MM. BOULLAND and ANDRAL, Dr. HOPE, and most other anatomists, are of opinion that the liver is composed of two substances,—of a red and a yellow substance: it will be shown hereafter that these two apparently different substances are identical in structure, the red colour resulting from congestion only.

* Op. cit.

† Part V.

The portal vein enters the liver in all the vertebrated animals, in all of which the lobules are arranged around the hepatic veins as I have described them in man. Each lobule is composed of a plexus of biliary ducts, of a venous plexus formed by branches of the portal vein, of a branch of an hepatic vein, and of minute arteries; nerves and absorbents, it is to be presumed, also enter into their formation, but cannot be traced into them.

The hepatic ducts, commonly so called, and their vaginal and interlobular branches constitute the excreting portion of the biliary apparatus; they are also organs of mucous secretion, being furnished with mucous follicles: the secreting portion of the liver is also composed of ducts, which form a plexus in each lobule. These plexuses may be called the lobular biliary, or secreting biliary plexuses. The ducts composing them being exceedingly minute, and always containing bile, much greater difficulty is experienced in injecting them than in injecting the blood-vessels of the liver, even in the usual manner; and this difficulty is not so easily overcome as that occasioned by blood in the vessels, for the bile contained in the excreting ducts is propelled by the injection into the secreting ducts, from which it has no exit by other vessels, and consequently opposes the entrance of the injection. This process is, to a certain degree, facilitated by tying the portal vein and hepatic artery in the living animal, and thereby arresting the secretion of the bile*. If this operation be carefully performed, the animal will survive several hours, during which time the ducts will discharge much of the bile they contained, and the liver will sometimes become almost colourless. The experiment will probably be attended with more success if performed a few hours after feeding the animal. After preparing the liver in this manner, I have frequently succeeded in partially injecting the lobules from the hepatic duct; I have also injected these bodies from the duct in the human subject, but with less success. Examined with the microscope, the injected interlobular ducts are seen dividing into branches, which, entering the lobules, divide and subdivide into minute ducts; these ducts anastomose with each other, forming a reticulated plexus. (Plate XXIII. fig. 3.) If an uninjected lobule be examined and contrasted with an injected lobule, it will be found that the acini of MALPIGHI in the former are

* It is probable that the *tubuli seminiferi* might be injected with facility in animals after arresting the secretion, by dividing the blood-vessels of the cord several days before killing the animal.

identical with the injected lobular biliary plexus in the latter, and the blood-vessels in both will be easily distinguished from the ducts. The ducts forming the plexuses, when examined with the microscope, present very much the appearance of cells ; and this appearance, which has been well delineated by MAS-CAGNI *, probably induced this anatomist to consider the liver as an assemblage of minute cavities, giving origin to the ducts. The form of the lobules bears no relation to the arrangement of the ducts, the form of each lobule being always correspondent to the branches of the intralobular hepatic vein occupying the centre of the lobule. The coats of the lobular ducts, on which the blood-vessels next to be described ramify, constitute the proper secreting substance of the liver, as the coats of the cortical ducts of the kidney, and those of the tubuli seminiferi, constitute the secreting substance of their respective organs.

The left lateral ligament may be considered as a rudimental liver, in which this organ presents itself to our examination in its simplest form. From that edge of the liver connected to the ligament, numerous ducts emerge, which ramify between the two layers of peritoneum of which the ligament is composed. These ducts were discovered by FERREIN, but this anatomist did not ascertain their termination. "*A l'égard des vaisseaux biliaires, M. FERREIN en a observés de nouveaux, dont les uns reviennent du ligament gauche du foye, et qu'il a vûs quelquefois repandus sur la face inférieure du diaphragme †.*" These ducts, the smallest of which are very tortuous in their course, divide, subdivide and anastomose with each other. They are sometimes exceedingly numerous, two or three of them in such cases being of considerable size ; some of them, as FERREIN says, frequently extend to the diaphragm and ramify on its inferior surface. They sometimes extend only half-way up the ligament, where they divide into branches, which, forming arches, return and descend towards the liver, anastomosing, or being continuous, with other ducts issuing from it. The spaces between the larger, or excreting, ducts are occupied by plexuses of minute, or secreting, ducts. (Plate XXIII. fig. 4.) I have injected the ducts on the inferior surface of the diaphragm, but have not succeeded in injecting them to their termination ; we may however conclude,

* Prodomo, Tab. VI. figg. 13, 14.

† Mémoires de l'Académie Royale des Sciences, Histoire, 1733.

that, like those just described, they form arches, the branches returning towards the ligament, and being continuous with others ascending from it. Branches of the portal and hepatic veins, with arteries and absorbents, also ramify in the ligament, which, including between its layers a plexus of secreting and excreting ducts, with blood-vessels ramifying on their parietes, admirably displays the structure of the liver*. FERREIN speaks of other ducts; "d'autres reviennent de cette portion des parois de la veine cave, qui paroît hors de l'échancrure sigmoïde du foye quand on le regarde par derrière, d'autres enfin reviennent des membranes de la vésicule du fiel." The inferior cava usually occupies a fissure at the back part of the liver; this fissure is frequently converted into a canal by a portion of the liver, extending from the lobulus Spigelii to the right lobe; frequently, also, the fissure is converted into a canal by a band, apparently of ligamentous texture, varying in width in different subjects. This band is, like the left lateral ligament, a transparent portion of the liver, containing ducts and blood-vessels. In a preparation in my possession, in which the ducts in this band are injected, a few injected ducts are seen issuing from the right lobe and ramifying on the coats of the cava above the band. The umbilical vein is also contained in a fissure, which is frequently converted into a canal by a process of the liver, called the *pons hepatis*, extending from the *lobulus quadratus* to the left lobe; sometimes the two lobes are connected by a band only, which is similar in structure to that behind the cava. No ducts ramify in the coats of the gall-bladder. It is probable that FERREIN mistook the absorbents of the gall-bladder for ducts, this anatomist, probably, having injected some of the former vessels, as I have frequently done, from the hepatic duct: or FERREIN may allude to ducts which occasionally ramify between the liver and gall-bladder, and divide into interlobular branches, which enter the former, and which he may have removed with the latter and mistaken for ducts ramifying upon it. No branches of the hepatic veins ramify in the coats of the gall-bladder; and the absence of these vessels sufficiently proves the non-existence of ducts. The cystic veins are branches of the abdominal portal, and not of the hepatic portal or umbilical, vein: they are therefore efferent, and not afferent, vessels, conveying blood from, and not to, the

* A beautiful preparation is made by drying the ligament on glass, after having injected the ducts with size or mercury.

gall-bladder: it necessarily follows, that biliary ducts ramifying on the parietes of this receptacle would receive the materials of their secretion from arterial blood,—that of the cystic arteries. If in any case ducts should be found on the gall-bladder, I venture to assert, that branches of both the portal and hepatic veins will also be found; but the portal veins in such a case will be branches of the hepatic portal vein, will convey blood from the coats of the excreting ducts, and to the coats of the secreting ducts, and not from the gall-bladder. If ducts, arteries, and one set only of veins, terminating in either the portal or hepatic veins, should be found,—and this is always the case if FERREIN'S assertion, that ducts ramify on the coats of the gall-bladder, be true,—then would the bile of these ducts at least be secreted, beyond dispute, from arterial blood.

Branches of the hepatic artery and portal vein accompany the ligamentum teres; these veins convey blood to the hepatic portal vein, and must therefore be considered as separate branches of the abdominal portal system.

Of the Lobular Venous Plexuses.—The interlobular branches of the portal vein, surrounding the lobules on every side except at their bases, divide into branches, which, entering these bodies, form in each of them a plexus, the branches of which terminate in the intralobular hepatic situated in the centre of the lobule. This plexus, interposed between the interlobular portal veins and the intralobular hepatic vein, constitutes the venous part of the lobule, and may be called the lobular venous plexus. Examined with a powerful microscope, the vessels constituting the plexus are seen converging from their origin at the circumference toward their termination at the centre of the lobule; they communicate with each other by smaller transverse branches, between which are seen minute circular, ovoid, or oblong spaces, occupied by portions of the lobular biliary plexus. (Plate XXIII. fig. 5.) Examined with a less powerful microscope, the vessels of the plexus appear arranged in circles. The circular, ovoid and oblong portions of the biliary plexus, seen between the branches of the venous plexus, are the acini of MALPIGHI. MÜLLER has delineated the converging vessels of the plexuses in the liver of the squirrel; but this anatomist did not ascertain whether they were branches of the portal vein or of the hepatic artery. “Præsertim examinare juvat, utrum vascula sanguinea descripta, inter acinos elongatos decurrentia, ad venam portarum an ad arterias pertineant, num sanguis inter acinos diffusus eadem ratione inferius

in venulas colligatur. Doleo, Sciurum hactenus novum defuisse, in quo quæstiones hæce vasis artificiose repletis possent extricari*." The venous plexus of one lobule communicates with the plexuses of the surrounding lobules by means of the intervening interlobular branches of the vena portæ, this vein thus forming one continuous plexus through the whole liver. The converging branches of each plexus unite at the centre of each lobule, and form an intralobular hepatic vein, this vein having no communication with the corresponding veins of the contiguous lobules, except through the medium of the intervening plexus and portal veins. No branches of the hepatic veins are found in any other part of the liver; occupying the centre alone of each lobule, their only office is to convey the blood from the lobular venous plexuses, and not from the arteries.

In consequence of its double venous circulation, the liver is naturally in a state of sanguineous congestion; hence arises the great difficulty of making successful injections of the human liver: the plexuses may, however, be frequently well, but seldom equally, injected, and always with greater success from the portal, than from the hepatic vein, the latter, and those portions of the plexuses immediately surrounding its intralobular branches, generally containing whatever blood may remain in the liver after death. The plexuses may be always injected with facility from the portal or hepatic veins, and the injection will pass freely from one vein into the other without extravasation, if the liver has been previously deprived of all its blood by the ligature of the portal vein and hepatic artery in the living animal†. Anatomists have consi-

* Op. cit., p. 80.

† I for some time experienced great difficulty in making successful injections of the minute vessels of the liver; and this difficulty, arising from the presence of blood in the vessels, was increased when my object was to inject the two veins in the same organ, no exit being then left for the blood. Very little advantage is gained by previously injecting warm water, a large portion of which remaining in the vessels dilutes the injection and obstructs its course. The object is to obtain a free passage for the injection through the minute vessels; this can be accomplished only by tying the portal vein and hepatic artery in the living animal, and thus depriving the liver of all its blood. In one minute after the application of the ligature, the liver becomes bloodless, and the sufferings of the animal may be abridged, and regurgitation into the hepatic veins prevented, by dividing the inferior cava near its termination in the right auricle. Before injecting, the body of the animal should be left in water during twenty-four hours, a ligature having been previously placed on the inferior cava above the diaphragm to prevent the entrance of the water into the hepatic veins. If the liver be previously prepared in this manner, all the intralobular hepatic veins may be injected with one colour, and all the interlobu-

dered, that the free communications which exist between the two vessels obviate the difficulty which would otherwise arise in the circulation through the liver, from the want of power consequent on the presence of the two veins*; and although the communications between these vessels appear, upon experiment, to be more free than those which exist between the hepatic artery and the portal vein, and between arteries and veins generally in other parts of the body, yet it appears that the arteries and veins in the spleen and kidney, and probably in all glands, communicate with equal freedom. The lobular venous plexus is best examined in the superficial lobules, but here again the human liver presents a difficulty, particularly in the adult, in consequence of the opacity of the proper capsule: the liver of the cat, and that of the smaller animals generally, appear to have no cellular capsule, and are consequently more favourable for this purpose.

The venous plexus ramifies on the biliary plexus: the blood circulating through it is composed of the portal blood, and certainly of that portion of the arterial blood which, having nourished the excreting ducts and supplied them with mucus, and having circulated through the vasa vasorum of all the vessels, becomes venous and is received into the branches of the portal vein, by which, with the portal blood, it is conveyed to the plexus; and from this mixed blood the bile is secreted.

The vessels of the plexus ramify on, or as MÜLLER says, between, the several portal veins with another, and the course and distribution of each set of vessels may be studied with facility. The various appearances produced by congestion of the liver may be imitated by injection. This method of injecting is equally applicable to every other organ. I made a very successful injection of the portal and hepatic veins in the exsanguine liver of a man, who died from the rupture of an aneurism of the abdominal aorta, under the care of Dr. HORN, in the Marylebone Infirmary. In the preparations of this liver, as in those made by injecting the vessels after the ligature of the portal vein and hepatic artery in living animals, the central portions of the lobules are coloured with blue, and the marginal portions with red injection.

* The *vis à tergo* is removed by the ligature of the portal vein and hepatic artery; these vessels, nevertheless, disembarass themselves perfectly of their blood, and no regurgitation takes place. In the sheep, the inferior cava runs in a direction parallel to the superior margin of the liver, a part of the right lobe of which is in front of this vein: the hepatic veins conveying the blood from this part terminate in the cava at obtuse angles; this blood consequently flows in an opposed direction to that passing through the cava. The collision of the two currents is prevented, and a septum is, to certain distance, formed between them by two valves, somewhat larger than those of the human aorta, situated at the orifices of the two right hepatic veins.

creting ducts; they are not continuous with the ducts as was imagined by RUYSCH. On this subject MÜLLER observes: "Itaque autopsia docet, vascula sanguifera tenuissima cum ductibus biliferis cæcis nullum commercium inire*. Neque verò quisquam commercium inter fines ductuum biliferorum et vascula sanguifera unquam observavit. Quod jam HALLERUS rectè monuit. Nemo vidit vasculum sanguiferum in finem ductûs biliferi usquam desinens†."

Of the Lobular Arteries.—The lobules are sparingly supplied with arterial blood. These bodies cannot be coloured with injection from the artery even in the young subject; in the adult, after the most successful injection, when the arteries of the cellular capsule, those of the excreting ducts and gall-bladder, and the vasa vasorum are minutely injected, a few injected vessels only are detected entering the lobules. I have frequently tied the thoracic aorta in living animals, thereby cutting off all supply of blood from the abdominal viscera; and in these animals, when injected from the aorta below the ligature forty-eight hours after death, the integuments, the secreting portions of the kidneys, the spleen, pancreas, intestines and pelvic viscera were coloured in a remarkable degree by the injection; on the surface of the liver a few vessels only could be discovered, this organ presenting a curious contrast with the surrounding coloured viscera. The gall-bladder and ducts were, however, equally well injected with the intestines; the vasa vasorum were also well injected. In these experiments it will be remarked, that the secreting portion alone of the kidney was highly injected; the excreting portion of this gland resembling the secreting portion of the liver in its supply of arterial blood, which it receives for nutrition only. Similar experiments were tried on birds, and in these animals all the viscera were highly injected, with the exception of the liver and kidneys, the latter organs in oviparous animals having, like the liver, a double venous circulation, the urine, as well as the bile, being secreted from venous blood‡. Whether the liver be injected from the aorta or from the hepatic artery, the appearances produced will be nearly the same. In

* Op. cit., p. 82.

† Ibid. p. 83.

‡ JACOBSON, De Systemate Venoso peculiari in permultis Animalibus observato. Hafniæ 1821. "On a peculiar Arrangement of the Venous System observed in many Animals," Edinburgh Medical and Surgical Journal, vol. xix. p. 78.

speaking of the excreting ducts, it was shown that these vessels are abundantly supplied with arterial blood, which is received by branches of the portal vein; the injection very commonly passes from the arteries into these branches, and thence into the trunks of the vein, and it occurred to me, that the injection thrown into the arteries was probably in this manner diverted from the lobules. To ascertain if such was the case, blue injection was first thrown into the portal vein; the arteries were then injected with red. On dissection, branches of the two sets of vessels were found in the coats of the vessels, and in those of the excreting ducts and gall-bladder; the lobules were coloured with the blue injection; the red was confined to their circumference, and appeared in points only. This experiment was varied by injecting the portal vein and its branches as far only as the entrance of the latter into the lobules, these bodies thus remaining uninjected. The injection propelled through the arteries had now free access to the uninjected lobules, and no exit by the injected portal vein; and the artery having no communication with the hepatic veins, the injection had no exit by these vessels: the lobules, however, were not better injected in this than in the preceding experiments. From these experiments I conclude, that the secreting portion of the liver, like the excreting portion of the kidney, is supplied with arterial blood for nutrition only. As all the branches of the artery of which we can ascertain the termination end in branches of the portal vein, it is probable that the lobular arteries terminate in the lobular venous plexuses formed by that vein, and not in the intralobular branches of the hepatic veins, which cannot be injected from the artery, the blood of these arteries, after having nourished the lobules, becoming venous, and thus contributing to the secretion of the bile.

MÜLLER is also of opinion that the ultimate reticulated vessels of the liver receive blood from the artery as well as from the portal vein: "*Vascula ultima reticulata sanguinem tam ab arteriis quam à venâ portarum accipere, venisque hepaticis reddere, ex hisce argumentis concludo: 1. Post injectionem in arteriam hepaticam non minùs quàm in venam portarum aut venas hepaticas factam, eadem communia vasculorum minimorum retia replentur, quod ex injectionibus exsiccatis LIEBERKÜHNIANIS, Berolini asservatis, facillè quisquis sibi persuadebit:*" from which it appears that LIEBERKÜHN injected the lobules from the artery, as well as from the portal or hepatic veins. I have

shown that the ultimate reticulated vessels, or those I have called the lobular venous plexuses, are formed by the portal vein alone; that the branches of the artery ramify in the coats of all the vessels; and that these arteries terminate in the branches of the portal vein: it would appear, therefore, that LIEBERKÜHN, if he injected the lobules from the artery, must have previously filled all the branches of the portal vein from that vessel*. MÜLLER's second argument is: "Injecti liquores colorati ex alio vasorum ordine facile in aliud trans-eunt, qualis frequens HALLERI veterumque, WALTERI denique et RUDOLPHII cet. extat experientia. Ipse equidem transitum aquæ limpidæ et coloratæ sæpius observavi†." MÜLLER coincides in opinion with those anatomists who suppose that all the blood-vessels communicate directly with each other. I have shown that no branches of the artery terminate in the hepatic veins, the latter vessels being injected from the former through the medium of the lobular venous plexuses of the portal vein.

Of the Red and Yellow Substances of FERREIN, and of the Appearances produced in the Liver by Congestion.—The structure of all the lobules is similar, and each lobule is of the same structure throughout; one part of a lobule is not more vascular than another; there is, therefore, no distinction of red and yellow substances in the liver; the red colour results from congestion only.

FERREIN first asserted the existence of two substances. "Sur la structure, il a trouvé dans chaque grain ou lobule du foye deux substances différentes; une qu'il appelle *corticale*, qui est extérieure, friable, et d'un rouge tirant sur le jaune; l'autre *médullaire*, ou intérieure, rouge, molle et pulpeuse, placée au centre de chaque grain, très-apparente dans plusieurs animaux, et souvent dans l'homme. Les conduits hépatiques traversent la substance corticale pour se rendre dans la substance médullaire, que M. FERREIN croit formée des extrémités pulpenses de ces canaux‡." FERREIN's opinion respecting the existence of two substances has been very generally adopted by anatomists; some, however, have disagreed with him respecting their relative position to each other. Thus, AUTENRIETH says the yellow substance is medullary, and the red corti-

* LIEBERKÜHN used injection made of white wax, resin and Venice turpentine. "Sur les Moyens propres à découvrir la Construction des Viscères," Mémoires de l'Académie Royale des Sciences de Berlin, tom. iv. p. 28. 1748.

† Op. cit., p. 82.

‡ Mémoires de l'Académie Royale des Sciences, Histoire, 1733.

cal. MAPPES, who was unacquainted with the lobular structure of the liver, which was known to FERREIN, says, "l'une de ces substances, qu'on peut appeler granulée, (médullaire, suivant AUTENRIETH,) forme des circonvolutions, tantôt semblables à celles des intestins, tantôt rameuses, plates et arrondies, de couleur jaune et assez denses, qui laissent entre elles des espaces arrondies d'un quart ou d'un travers de ligne de diamètre, ou des fissures oblongues le tout rempli par la seconde substance, laquelle est brune et moins serrée et qu'on peut appeler cellulo-vasculaire (corticale, suivant AUTENRIETH) *." To MECKEL †, the view taken of the substances by AUTENRIETH and MAPPES appears more just than that taken by FERREIN. RUDOLPHI says the terms cortical and medullary are not applicable to the substances, one not forming a bark for the other. The attention of pathologists has been lately directed in a particular manner to these supposed elements of the liver by MM. BOULLAND and ANDRAL. BICHAT, who thought it "impossible that all the substance of the liver is destined to secrete bile," was of opinion that the bile is secreted from arterial blood alone, and that the liver fulfils another function connected with the existence of the vena portæ ‡. On this subject M. BOULLAND remarks, "Si cette opinion est vraie, elle doit s'accorder avec l'anatomie du foie, c'est-à-dire, que si cet organe est chargé d'une fonction de plus que celle de la sécrétion de la bile, et que cette fonction ait rapport à la circulation sanguine, ou doit y trouver un appareil vasculaire spécialement destiné à ce dernier usage, en outre de l'appareil sécréteur de la bile." In speaking of the substances, the same pathologist says, "La substance jaune se présente sous forme de granulations saillantes, dont la figure, la couleur et l'arrangement doivent les faire regarder comme les grains sécréteurs de la bile, connus depuis long-temps sous la dénomination d'*acini*. . . . Ces granulations sont entourées de toutes parts par la substance brune, qui affecte par cela même diverses formes angulaires. . . . Cette substance, qui est toujours déprimée au-dessous du niveau des granulations jaunes, n'est pas seulement formée de tissu cellulaire, mais encore d'un lacis vasculaire, qui peut être comparé au tissu érectile §." M. BOULLAND con-

* Loc. cit.

† Manuel d'Anatomie, tom. iii. p. 452.

‡ Anatomie Générale, tom. ii. p. 260.

§ "Considérations sur un Point d'Anatomie Pathologique du Foie," Mémoires de la Société Médicale d'Émulation, tom. ix. p. 177.

siders that the *Cirrhose* of LAENNEC depends on a disassociation of the two elements; the appearances he has represented in fig. 1, and which, as he remarks, are frequently observed in connexion with disease of the heart, resemble some of those delineated by MÜLLER in Tab. XI., and arise from sanguineous and biliary congestion. M. ANDRAL coincides with M. BOULLAND in his opinion of the two elements, and says, "Isolées, ou réunies et combinées de plusieurs manières, les altérations de ces deux substances produisent les divers états morbides du parenchyme hépatique*." M. ANDRAL considers the red substance as "éminemment vasculaire †, . . . où se ramifie surtout le système capillaire de l'organe ‡." Opinions opposed to those just cited are entertained by PORTAL, MÜLLER, and M. CRUVEILHIER. PORTAL merely observes, that "FERREIN avait avancé gratuitement que les glandes du foie étoient composées de deux substances, l'une corticale, et l'autre médullaire§." M. CRUVEILHIER, in his admirable work on pathological anatomy, says, "Il n'existe pas deux substances dans le foie, soit qu'on admette deux espèces de granulations, soit qu'on admette que chaque granulation est composée des deux substances à la fois. Ce qui a pu en imposer à cet égard, c'est que la partie centrale de chaque granulation répond au radicule biliaire, et conséquemment est souvent teinte en jaune, et que la partie excentrique répond à l'élément vasculaire, et conséquemment est plus rouge que la partie centrale ||." MÜLLER gives the following account of the two substances. "Diversam substantiam hepatis, utpote medullarem et corticalem, quæ per hepar totum undique obveniunt, qualem AUTENRIETH, BICHAT, CLOQUET, MAPPES atque etiam J. FR. MECKEL admittunt, equidem neque in historia evolutionis amphibiorum et avium, neque in hepate adultorum microscopicè observato, conspexi. Historia evolutionis hanc quæstionem evidentissime illustrat. Systema nimirum ductuum biliferorum in embryone amphibiorum et avium liberis finibus in superficie hepatis prominulis conspicuum. Sarmentula illa foliatim et paniculatim divaricata, colore e gilvo candido nitent, magnopere ab interstitiis sanguinolentis distincta. Hinc sane duplicis substantiæ species exoritur, quoniam circum duc-

* Clinique Médicale, 2de Edition, tom. iv. p. 178.

† Ibid., p. 176.

‡ Précis d'Anatomie Pathologique, tom. ii. p. 584.

§ Anatomie Médicale, tom. v. p. 277.

|| Anatomie Pathologique du Corps Humain, Livr. xii. "Foie granuleux."

tuum biliferorum surculos et fines undique tela vasculosa subtilis sanguifera disponitur, ita ut interstitia ductuum biliferorum a tela conjunctiva expleantur, quæ et subtilissimis fere constat vasculorum sanguiferorum retibus, in quibus arteriæ et venulæ advehentes in revehentes venas transeunt. Atque hæc sola est utriusque substantiæ notio. Sed in omnibus organis glandulosis fere idem obvenit *."

My attention was first directed to the anatomy of the liver by the study of the admirable works of M. ANDRAL. In the first organs I examined, I found the small branches of the hepatic veins ramifying exclusively in the red, and those of the portal vein in the yellow substance. I concluded that the liver was composed of two venous trees, a portal and an hepatic tree, the former having a cortex of yellow, the latter of red substance; and with M. BOULLAND I thought it probable that the red substance was the organ of the function imagined by BICHAT. I next ascertained the lobular structure, and concluded with FERREIN that the red substance was medullary, and the yellow cortical. Subsequent dissections, in which I found branches of both the portal and hepatic veins ramifying in the red substance, tended to unsettle the opinions I had formed respecting the anatomy and physiology of the two substances; and these opinions were finally overturned by the examination of a liver in which I found the branches of the portal vein alone ramifying in the red, and those of the hepatic veins in the yellow substance. The only conclusion that could be drawn was, that the red colour resulted from congestion; that it was medullary, occupying the centre of each lobule, when the hepatic, and cortical, forming the circumference, when the portal vein, was congested. It occurred to me that the kidneys of birds having, like the liver, a double venous circulation, were equally subject to congestion, and would, like it, present an appearance of two substances. Dissection verified this conjecture; but the apparently two substances are red, one, however, being of a much deeper colour than the other. I have satisfied myself by repeated injections, by examination with the microscope, and by experiments on living animals, that the lobules are of the same structure throughout; that one portion of a lobule is not more vascular than another; that the acini of MALPIGHI, by contrast with the congested vessels, are even more apparent in the red than in the yellow

* Op. cit., p. 83.

substance; and that these supposed two substances are consequently identical in structure. That secreting biliary ducts are contained in the red as well as in the yellow substance, is proved by the relation given by M. ANDRAL of a case of jaundice with "coloration insolite du foie." "Foie volumineux, pesant, très-dur, se déchirant difficilement, offrant une teinte générale d'un brun verdâtre. En l'examinant avec plus d'attention, on trouve que cette teinte n'est pas uniforme, et que le parenchyme du foie est formé, 1°. par un tissu d'un blanc verdâtre, disposé sous forme de lignes ou de plaques irrégulières (c'est le tissu blanc ordinaire hypertrophié); 2°. par un tissu d'un vert brun foncé, duquel dépend la couleur générale que présente le foie, et qui est l'analogue du tissu rouge ordinaire*." This was a case of vitiated biliary secretion, with general biliary and partial sanguineous congestion. The ordinarily yellow substance was of a greenish white colour, being congested with greenish bile only; the ordinarily red substance was of a deep brownish green, this colour evidently resulting from biliary and sanguineous congestion combined. I have met with more than one case of this kind; I have also seen cases of jaundice in which there was no biliary congestion of the liver, and the highest state of biliary congestion without jaundice. In attempting to estimate the causes of the various shades of colour observed in the liver, it is not sufficient to examine the cystic bile alone; the hepatic bile should be also examined, and it will be generally found, as in the above case, that these shades of colour depend either on biliary or sanguineous congestion alone, or on the various combinations of both.

Sanguineous congestion of the liver is either general or partial. In general congestion the whole liver is of a red colour (Plate XXI. fig. 6.), but the central portions of the lobules are usually of a deeper hue than the marginal portions. (Plate XXI. fig. 5.) Partial congestion is of two kinds, hepatic-venous and portal-venous congestion. Of the first kind there are two stages. In the first and most common stage, the hepatic veins, their intralobular branches and the central portions of the plexuses are congested. The congested substance is in small isolated patches of a red colour, and, occupying the centres of the lobules, it is medullary; the non-congested substance is of a yellowish white, yellow or greenish colour, according to the quantity and quality of the bile it contains:

* Clinique Médicale, 1ère Edition, tom. iv. p. 169.

it is continuous throughout the liver, and, forming the marginal portions of the lobules, is cortical. (Plate XXI. fig. 2.) This is passive congestion of the liver; it is the usual and natural state of the organ after death, and probably arises from its double venous circulation. In the second stage, the congestion extends through the plexuses to those branches of the portal vein situated in the interlobular fissures, but not to those in the spaces, which being larger than, and giving origin to, those in the fissures, are the last to be congested; when these vessels contain blood, the congestion is general, and the whole liver is red. In this second stage, the non-congested substance appears in isolated circular and ramous patches, in the centres of which the spaces and fissures are seen. (Plate XXI. fig. 3.) This is active congestion of the liver; it very commonly attends disease of the heart, and acute disease of the lungs or pleuræ: the liver is larger than usual in consequence of the quantity of blood it contains, and is frequently at the same time in a state of biliary congestion, which probably arises from the sanguineous congestion. Although in the first stage, the central portions of the plexuses, and in the second, the greater portion of each plexus and those branches of the portal vein occupying the fissures, are congested, and although the plexuses are formed by the portal vein; yet, as this form of congestion commences in the hepatic veins and extends towards the portal vein, and as it is necessary to distinguish this form from that commencing in the portal vein, the term of hepatic-venous congestion will not probably be deemed inapplicable to it. Portal-venous congestion is of very rare occurrence; I have seen it in children only. In this form, the congested substance never assumes the deep red colour which characterizes hepatic-venous congestion; the interlobular fissures and spaces and the marginal portions of the lobules are of a deeper colour than usual; the congested substance is continuous and cortical, the non-congested substance being medullary and occupying the centres of the lobules. (Plate XXI. fig. 4.) The second stage of hepatic-venous congestion, in which the congested substance appears, but is not, cortical, may be easily confounded with portal-venous congestion.

The physiological deductions arising out of the preceding anatomical facts are extremely simple. If it could be shown that two substances exist in the liver, it might be fairly presumed that this organ executes two functions; but each lobule being, in itself, a perfect gland, and of the same structure through-

out, each lobule, and consequently the whole liver, executes but one function, the secretion of bile*.

It has been shown that all the vasa vasorum of the liver are branches of the hepatic artery and portal vein; that branches of the portal vein arise in the coats of the hepatic veins themselves; and that the veins of the coats of the vessels constitute the hepatic origin of the portal vein. The arterial blood having circulated through the coats of the vessels, becomes venous, and is conveyed by the veins arising in the coats of the vessels into those branches of the portal vein which correspond to the vessels in the coats of which the veins arise: thus, from the coats of the vaginal ducts, veins and arteries they convey the blood into the vaginal veins; and from the coats of the interlobular ducts, veins and arteries into the interlobular veins. From the coats of the hepatic veins and inferior cava, the blood is conveyed into the interlobular portal veins. In the vaginal and interlobular veins, the blood conveyed from the coats of the vessels becomes mingled with the proper portal blood. This mixed blood is conveyed by the interlobular veins into the lobular venous plexuses, in which the lobular arteries probably terminate, after having nourished the secreting ducts. From the mixed blood circulating through the plexuses, the bile is secreted by the lobular or secreting biliary plexuses.

* M. VOISIN (Nouvel Aperçu sur la Physiologie du Foie) has lately revived an old opinion respecting the physiology of the liver. The absorbents of the liver are, according to M. VOISIN, of two kinds, the lymphatics and the chyliferous vessels: the former arise in the tissue of the liver and ramify on its surfaces; the latter are continuous with the chyliferous vessels of the intestines; they accompany the portal vein, and convey a portion of the chyle into the liver, in which, according to M. VOISIN, it undergoes a certain change, and is conveyed from the liver into the receptaculum chyli by (as it would appear from M. VOISIN's description) the same vessels. M. VOISIN makes no mention of the valves of his chyliferous vessels, or of the impossibility of injecting these vessels, except by rupturing the valves, from the lesser omentum upwards towards the liver; but he asks, "S'il n'en était pas ainsi de l'origine et du trajet de ces vaisseaux lactés, d'où viendraient ceux qu'on remarque dans le foie, de quelle utilité lui seraient-ils?" If the abdomen of a dog be opened during the period of the absorption of the chyle, no part of this fluid will be found in the absorbents (the chyliferous vessels of M. VOISIN), which leave the liver at the transverse fissure and descend, covered by the peritoneum of the right edge of the lesser omentum, to enter a lymphatic gland situated near the duodenum. If a ligature be placed on the vessels near the duodenum, the absorbents above the ligature will, in a few minutes, become turgid; if the ligature be loosened, the turgid vessels will soon resume their natural appearance. If the ligature be placed on the vessels near the transverse fissure, the absorbents below the ligature, being no longer supplied with fluid from the liver, will collapse and be no longer perceptible.

The blood which enters the liver by the hepatic artery fulfils three functions: it nourishes the liver; it supplies the excreting ducts with mucus; and, having performed these purposes, it becomes venous, enters the branches of the portal vein, and contributes to the secretion of the bile. The portal vein fulfils two functions; it conveys the blood from the artery, and the mixed blood to the coats of the excreting ducts. It has been called the *vena arteriosa*, because it ramifies like an artery, and conveys blood for secretion; but it is an arterial vein in another sense, being a vein to the hepatic artery, and an artery to the hepatic vein. The hepatic veins convey the blood from the lobular venous plexuses into the vena cava inferior.

FERREIN was evidently well acquainted with the hepatic circulation; it is to be regretted that his "Mémoire sur la Structure et les Vaisseaux du Foye" was not published. The following account of the vessels is given from his description of them. "A l'égard des vaisseaux sanguins, il a observé que les divisions et les subdivisions de la veine-porte donnent deux sortes de rameaux, les uns veineux et les autres artériels: il nomme rameaux artériels ceux qui sont connus par leur fonction de porter le sang de la veine-porte dans le foye: il a découvert les veineux, et ceux-ci reçoivent le sang de l'artère hépatique, et le conduisent dans les rameaux artériels de la veine-porte, de ceux-ci dans la substance médullaire des lobules, et de-là dans les branches de la veine-cave*." It does not appear that WALTER ascertained the termination of any of the branches of the artery; he supposed that some branches of this vessel pour arterial blood into the portal vein; he says, "Extremitates ultimæ arteriarum in hepate evanescunt, ita, ut nonnullæ earum, partim in cellulosa hepatis interna terminentur, hinc illam nutrant, partim sub forma fasciculorum florum, vel potius in directione fere stellari in reliquam hepatis substantiam se dispergentes, ramulos venæ portarum perforant, in eorum cavum sese aperiant, ibique tandem liquidum quoddam ad bilem idoneum magis perficiendam secernunt: reliqui rami, ramos venæ cavæ et ductus hepatici elegantissimo reticulo vasculoso, irretiunt†." Of the functions of the artery, the same anatomist says, "Officium ergo arteriæ hepaticæ duplex erit, vel substantiam cellulosam

* Mémoires de l'Académie Royale des Sciences, Histoire, 1733.

† De Hepate, p. 96, in Annotationes Academicæ, Berolini 1786.

membranasque vasorum hepatis nutrire, vel partem aliquam bili necessariam secernere et in ipsam venam portarum deponere *."

M. SIMON† concluded from his interesting and ably conducted experiments, that the bile is secreted from the portal blood alone; and Mr. PHILLIPS arrived at the same conclusion from the issue of two experiments in which he tied the hepatic artery, the details of which are in the possession of the Royal Society. From the issue of three experiments in which the portal vein was tied, and in in which bile was secreted, and from the cases related by Mr. ABERNETHY and Mr. LAWRENCE, Mr. PHILLIPS concluded that bile might be secreted from arterial blood alone‡. I have shown that the bile is secreted from venous blood alone, this blood being composed of the two streams which enter the liver by the portal vein and hepatic artery; and from the anatomical details into which I have entered, it is evident that bile will be secreted, but in different quantity, whether the vein or the artery be tied, and from venous blood in both cases. The quantity of arterial blood conveyed to the liver is so small, and death so soon follows the ligature of the vein, that in experiments on rabbits and kittens, in which I tied the vein, I cannot say that bile was secreted.

It appears to have been satisfactorily ascertained by TIEDEMANN and GMELIN§, and by M. VOISIN||, that the bile is a purely excrementitious fluid, stimulating the intestinal canal, but having no influence on the formation of the chyle. The lungs separate from venous blood an excrementitious matter in a gaseous form; the liver, extracting from venous blood an excrementitious fluid, may be considered as the abdominal lung.

A few eminent physiologists, founding their opinion on false anatomical data, on the cases related by Mr. ABERNETHY and Mr. LAWRENCE, and on the absence of the hepatic-portal vein in the invertebrated animals, in which the liver is supplied with arterial blood only, maintain that the bile is secreted from arterial blood. Since the conclusions contained in this paper respecting the

* De Hepate, p. 105, in Annotationes Academicæ, Berolini 1786.

† Nouveau Bulletin des Sciences par la Société Philomatique de Paris, 1825. Edinburgh Journal of Medical Science, No. 1. p. 229. Birds are better adapted for these experiments than the mammiferous animals, the portal vein in the former animals communicating freely with the posterior cava. M. SIMON performed his experiments on pigeons.

‡ London Medical Gazette, June 29, 1833.

§ Recherches sur la Digestion, 2de Partie, p. 58.

|| Op. cit.

physiology of the liver were first submitted to the Society, I have been enabled, through the kindness of Mr. STANLEY, to examine the liver of the child in which Mr. ABERNETHY found that the portal vein terminated in the inferior cava. Mr. ABERNETHY's account of the case is contained in the Philosophical Transactions for 1793. Mr. GREEN, in his anatomical lectures, had always described this case, as presenting less anomaly than was commonly supposed. He considered that the umbilical vein ramified through the liver, that the artery probably terminated in it, and that the vein and not the artery conveyed the blood to the secreting part of the liver. Sir CHARLES BELL also, in speaking of this case, makes the following highly interesting observations: "We may observe on this case, that it does not prove the bile to be, in the natural economy, secreted by the arteries and not by the vena portæ; for the artery here was unusually large, so that it performed a function in this instance which it does not usually perform. Had the artery been of the usual size, we might then have concluded that the vena portæ was distributed to the liver to serve some lesser use in the economy of the system, and that it did not secrete the bile. The liver, it is said, was of the ordinary size. Now as the bulk of the liver is, in its natural state, made up of the dilated veins, it is some proof of what I should imagine had taken place here, that by some provision of the vessels, the arterial blood had been diffused, and the celerity of its motion checked previous to its ultimate distribution. Nay, it may have opened into the branches of veins answering to the extremities of the vena portæ. I conclude, that this singular and interesting case may strengthen the opinion which some have entertained, that the extreme branches of the hepatic artery pour blood into the extremities of the vena portæ previous to this formation of the bile by these veins; but it still leaves us with the general conclusion, that the peculiarities in the distribution of the vena portæ are a provision for the secretion of the bile, and that the branch of the aortic system, the hepatic artery, is otherwise necessary to the support of the function of the liver*."

I examined the liver of this child, which had not been examined by Mr. ABERNETHY, in the presence of Mr. STANLEY, Mr. MAYO, and several other gentlemen, in the Museum of Saint Bartholomew's Hospital. Mr. ABERNETHY had injected the arteries with red, and the hepatic veins with yellow size. As had

* The Anatomy and Physiology of the Human Body, vol. iii. p. 330.

been happily conjectured by Mr. GREEN and Sir CHARLES BELL, we found the open and uninjected ramifications of the umbilical vein (the hepatic-portal vein) accompanying, as usual, the branches of the hepatic artery and duct. By making sections of portal canals, we found the arteries, as Mr. ABERNETHY had described them, much larger than usual. In ordinary cases one principal artery is found in each canal; in this case two, and in some places three arteries of equal calibre were found in each canal. The branches of the umbilical or portal vein, which are usually so much larger than those of the artery, were found, on the surfaces of sections of this liver, to be, as nearly as we could judge, equal in calibre to the united dimensions of the two or three arteries which accompanied each branch of the vein. BICHAT, in support of his opinion that the bile is secreted from arterial blood, says, "On dit que le volume du foie est considérable, à proportion de l'artère hépatique : cela est vrai ; mais ce n'est pas au volume de ce viscère qu'il faut comparer celui de cette artère pour savoir si elle fournit les matériaux de la sécrétion, puisque nous avons vu qu'il est impossible que toute sa substance soit destinée à séparer la bile. C'est avec les conduits biliaires et leur réservoir qu'il faut établir la comparaison : or, cette artère est exactement proportionnée à ces conduits ; il y a entre eux à-peu-près même rapport qu'entre la rénale et l'urètre ; au contraire, les conduits biliaires sont bien manifestement disproportionnés à la veine porte *." BICHAT's opinion, and the argument here offered in support of it, are completely refuted by the dissection of the liver in this case. The branches of the duct were much smaller than those of the artery ; in one canal, in which there were three arteries of equal dimensions, the duct was of about half the size of one artery. (Plate XXI. fig. 6.) This case, therefore, does not establish an analogy between the biliary organs of the vertebrated and invertebrated animals ; but, on the contrary, it shows that the class of monstrosities to which it belongs, forms a much slighter deviation from the ordinary vertebrated type than was imagined†. Nor does it militate against the conclusions maintained in this paper upon the physiology of the liver ; although, as Mr. MAYO observed, it cannot be supposed that the arterial blood, in its passage through the vasa vasorum into the branches of the umbilical vein, underwent the usual change into venous blood ; and it

* Anatomie Générale, tom. ii. p. 260.

† MECKEL, Manuel d'Anatomie, tom. ii. p. 538. I. GEOFFROY SAINT-HILAIRE, Histoire des Anomalies, tom. i. p. 456.

was still, he contended, arterial blood, though less pure in character, which was conveyed through venous canals into the secreting part of the liver.

A case, similar to Mr. ABERNETHY's, which was met with by the late Mr. WILSON, is mentioned by Mr. LAWRENCE * and Dr. MONRO †. The history of this case was lately read at a Meeting at the College of Physicians, by Dr. WILSON, to whom I am indebted for the following particulars. The subject was a girl, thirteen years of age, who met with her death from an injury of the head. The vena portæ terminated in the inferior cava; there were two splenic veins, one of which entered the portal vein, and the other the cava near the point where it becomes surrounded by the liver. Mr. WILSON says, "I could trace no vein passing into the liver at the cavity of the portæ; the remains of the umbilical vein were impervious; I traced them to the entrance of the portæ, and now regret that I had not traced them sufficiently far to see with what set of vessels they were united. The hepatic artery," Mr. WILSON continues, "came off in a distinct trunk from the aorta, and ran directly to the liver: it was much larger than it usually is, but not so large as the trunk of the vena portarum; it entered the liver as usual. The gall-bladder had nothing remarkable in its appearance: it was of a size proportioned to that of the liver, and contained more than half an ounce of bright yellow fluid, similar in appearance to the bile; it was not, however, submitted to any other test but that of sight." The umbilical vein in this case was obliterated as far as it was traced by Mr. WILSON; but, as in Mr. ABERNETHY's case, its hepatic branches were doubtlessly open, and received the blood from the artery, which they conveyed to the coats of the secreting ducts. No portion of the liver was preserved ‡.

While engaged in the examination of the natural structure of the Liver, I have not been inattentive to the changes produced in it by disease; and, with the permission of the Society, I propose submitting to its consideration a paper on the Morbid Anatomy of this organ.

* Medico-Chirurgical Transactions, vol. v. p. 174.

† Elements of Anatomy, vol. ii. p. 564. 1825.

‡ In the case related by LIEUTAUD after BAUHIN (Historia Anatomico-Medica), the liver and spleen, it is said, were wanting, the portal vein terminating in the inferior cava. The case related by HUBER (Programma sistens Observationes aliquot Anatomicas), which, in the Index to SANDIFORT's Thesaurus Dissertationum, is entitled "Diaphragmatis Habitus singularis," was, as MECKEL and RUDOLPHI observe, probably a case in which the hepatic veins perforated the diaphragm previously to entering the cava, and not an unusual termination of the portal vein, as has been supposed by some anatomists.

Explanation of the PLATES.

PLATE XX.

Fig. 1. A. An hepatic vein.

B. Lobules arranged around the intralobular branches of the hepatic veins, as they are frequently seen at the posterior part of the concave surface of the liver. This arrangement is more distinctly seen in the liver of the sheep than in the human liver. These lobules are parallel to the surface.

Fig. 2. Displays the three sets of branches constituting the hepatic veins.

A, A, A. The intralobular hepatic veins.

B, B. The sublobular-hepatic veins, in which the intralobular veins terminate.

C, C. Hepatic trunks, in which no intralobular veins terminate.

D. The mouths of intralobular veins opening into the sublobular veins.

E. The mouths of small sublobular veins.

F. The mouths of large sublobular veins.

Fig. 3. A longitudinal section of sublobular-hepatic veins, with lobules arranged around them.

A, A. Sublobular-hepatic veins.

B, B. Longitudinal sections of lobules, presenting a foliated appearance.

C, C. The bases of the lobules resting on the sublobular veins, and forming the canals containing them. The bases of the lobules are connected to the sublobular veins by the intralobular veins.

D. The external or capsular surfaces of the lobules.

E, E. The intralobular veins running through the centres of the lobules.

F. The projecting processes of the lobules, with their veins terminating in the central vein. The intralobular veins correspond in form with the lobules, the number of smaller veins being equal to the number of processes.

G. The mouths of intralobular veins opening into the sublobular vein.

Fig. 4. A. An oblique section of a sublobular-hepatic vein.

B, C, D, E, F, G. As in the preceding figure.

H. The bases of other lobules seen through the coats of the vein, and forming the canal in which the vein is contained. The centre of the base of each lobule is occupied by an intralobular vein.

I. The interlobular fissures seen through the coats of the vein.

Fig. 5. Longitudinal sections of an internal, and of two superficial lobules.

A. A sublobular-hepatic vein.

B. The convex surface of the liver.

C. An internal lobule, in which the smaller veins are seen commencing about the middle of the processes of the lobule, the substance of which completely surrounds them. The intralobular vein is also surrounded, except at the base of the lobule, where it makes its exit to terminate in the sublobular vein.

D. Two superficial lobules.

E. An intralobular vein commencing at the surface of the liver.

F, F. Two smaller veins, commencing at the surface and terminating in

G. An intralobular vein commencing at the surface. The superficial lobules are perforated by the intralobular veins, and when compared with the internal lobules, appear as if their upper portions had been removed.

H, H. The substance of the liver, formed by other lobules.

Fig. 6. A. A transverse section of a lobule.

B. The divided central intralobular vein.

C. The smaller veins, terminating in the central vein.

Fig. 7. A. A transverse section of a double lobule.

B, B. The smaller veins, terminating in

C. The divided central veins.

PLATE XXI.

Fig. 1. A. Angular lobules in a state of anæmia, as they appear on the external surface of the liver.

B. The interlobular spaces containing the larger interlobular branches of the hepatic duct, portal vein and hepatic artery.

C. The interlobular fissures, in which the smaller interlobular branches of the hepatic duct, portal vein and hepatic artery ramify.

D. Intralobular veins, occupying the centres of the lobules.

E. Smaller veins, terminating in the central veins.

Fig. 2. A. Rounded lobules in the first stage of hepatic-venous congestion, as they appear on the external surface of the liver.

B & C. The interlobular spaces and fissures; they are larger than those represented in the preceding figure, and contain more cellular tissue.

D. The congested intralobular veins.

E. Appearances produced by congestion of the intralobular hepatic veins, and of the central portions of the lobular venous plexuses, and constituting the medullary substance of FERREIN, the cortical substance of AUTENRIETH, the red substance of MM. BOULLAND, ANDRAL and other anatomists, and the cellulo-vascular substance of MAPPES. These appearances may be produced by injecting the central portions of the plexuses from the hepatic veins.

F. The non-congested marginal portions of the lobules, constituting the cortical substance of FERREIN, the medullary substance of AUTENRIETH, the yellow substance of MM. BOULLAND and ANDRAL, and the granular substance of MAPPES.

Fig. 3. A. Lobules in the second stage of hepatic-venous congestion, as they appear on the external surface of the liver.

B & C. Interlobular spaces and fissures.

D. The congested intralobular veins.

E. Appearances produced by more extensive congestion of the lobular venous plexuses. It will be remarked that in this, as in the preceding, figure, the intralobular veins and the central portions of the lobules are congested, but that, in this figure, the congestion is not confined to the centres of the lobules; that it extends to their margins and to those branches of the portal vein which ramify in the interlobular fissures; the congested substance is

consequently continuous, and the non-congested substance is in isolated patches. As the congestion extends from the hepatic to the portal vein, and as those branches of the portal vein contained in the fissures are smaller than those contained in the spaces, those in the fissures are congested before those in the spaces; the fissures are, therefore, in many parts rendered obscure, in consequence of the congested state of the smaller interlobular portal veins contained in them, and of the corresponding marginal portions of the lobules: the congestion not having extended to the veins in the spaces, those portions of the lobules immediately surrounding them are not congested. This is the red or medullary substance of FERREIN, now appearing cortical; in the preceding figure it appeared medullary; in this, it is continuous throughout the liver; in the preceding figure it was in isolated patches. This appearance also may be produced by injecting the plexuses from the hepatic veins.

- F. Non-congested portions of lobules, much resembling, in some parts, transverse sections, and, in other parts, longitudinal sections of single lobules. These apparently whole bodies are composed of the non-congested, opposite, marginal portions of three or four contiguous lobules, the congestion not having extended to the portal veins ramifying in the spaces and fissures which are seen between the different portions of which they are formed. They are of a yellowish white or yellow colour, according to the quantity and quality of the bile they contain. These are the bodies represented by MÜLLER, Tab. XI. fig. 11, by M. BOULLAND, Plate II. fig. 1. and by Dr. HOPE, figg. 104 and 105. This is the non-congested, or yellow, substance now appearing medullary, and in isolated patches; in the preceding figure it appeared cortical and continuous. This is the nutmeg liver of pathologists, the hypertrophy of the red substance of M. ANDRAL.

Fig. 4. A. The lobules as they appear on the surface in a state of portal-venous congestion.

- B. The interlobular spaces and fissures ; they are of a darker colour than those represented in fig. 2, in consequence of the congested state of the interlobular branches of the portal vein.
- C. The intralobular hepatic veins ; containing no blood, they are smaller, and of a lighter colour than those represented in figg. 2 and 3.
- D. The central portions of the lobules in a state of anæmia. This is the yellow or non-congested substance appearing medullary, and arising from non-congestion of the intralobular veins, and of the central portions of the lobular venous plexuses.
- E. The marginal portions of the lobules in a congested state. This is the congested substance appearing cortical and continuous, as in the preceding figure, but arising from a different cause,—from congestion of the interlobular branches of the portal vein and of the marginal portions of the lobules. This appearance may be produced by injecting the marginal portions of the lobular venous plexuses from the portal vein.

Fig. 5. A transverse section of a large portal canal and its vessels. The lobules are in a state of general congestion, their central portions being more congested than their marginal portions.

- A. Superficial lobules forming the parietes of the canal. They are similar to those of the external surface, being perforated by their intralobular veins. Some are observed in which these veins do not extend to the capsular surfaces of the lobules, this appearance depending on the direction in which the incision is made.
- B. Internal lobules not entering into the formation of the parietes of the canal. In these lobules the intralobular veins are completely surrounded by the substance.
- C. A transverse section of a portal vein.
- D. Vaginal branches arising from the vein, and dividing into interlobular branches, which enter the interlobular spaces.
- E. A transverse section of an hepatic duct.

- F.** A vaginal branch arising from the duct, and dividing into interlobular branches which enter the spaces.
- G.** The artery.
- H.** A vaginal branch arising from the artery, and dividing into interlobular branches which enter the spaces.
- I.** Three interlobular vessels, a duct, vein and artery entering each interlobular space.
- J.** The vaginal plexus, formed by the vaginal branches of the duct, vein and artery. The internal surface of the plexus is in contact with the large vessels; its external surface is in contact with the parietes of the canal. The vessels forming the plexus ramify in cellular tissue, which, with the vessels, constitutes the vaginal portion of Glisson's capsule. The capsule in these larger canals completely surrounds the three vessels.

Fig. 6. Represents a transverse section of a small portal canal and its vessels. The lobules are in a state of general congestion.

- a.** The portal vein, a great portion of which is in apposition with the interlobular spaces on the parietes of the canal.
- b.** The interlobular branches arising from the trunk and entering the spaces, with the branches of the duct and artery, without ramifying in the canal. On this side the vein resembles an hepatic vein in having no vaginal branches.
- c.** Two vaginal branches arising from the vein, and dividing into interlobular branches on that side of the canal on which the vein is separated from the spaces by the duct and artery. On this side, the vein, giving off vaginal branches, and being separated from the parietes of the canal by the capsule and vessels, resembles the larger portal veins.
- d.** The duct giving off vaginal branches.
- e.** The artery giving off vaginal branches.
- f.** Three vessels, a duct, vein and artery, entering each interlobular space on the surface of the canal.

PLATE XXII.

Fig. 1. A longitudinal section of a small portal vein and canal; the lobules are in a state of anæmia.

- A, A.** Portions of the portal canals, from which the vein has been removed. The parietes are composed of lobules, similar to those of the external surface of the liver, separated from each other by fissures and spaces.
- B.** The portal vein; the lobules and fissures are seen through its coats.
- C.** Mouths of interlobular veins, which, arising immediately from the portal vein, enter the spaces without forming a plexus. This portion of the vein, giving off no vaginal branches, and consequently having no capsule, resembles in these respects an hepatic vein.
- D.** Two larger orifices. These are the mouths of vaginal veins which enter the canal, and divide into two, three, or more interlobular branches.
- E, E.** The orifices of small portal veins, which enter other canals.
- F.** Vaginal branches arising from the vein and forming a plexus on that side of the canal occupied by the duct and artery. These branches are seen dividing into branches, which enter the spaces covered by the duct and artery.
- G.** The hepatic duct, giving off vaginal branches.
- H.** The hepatic artery, giving off vaginal branches.

Fig. 2. A longitudinal section of an hepatic vein. The lobules are in the first stage of hepatic-venous congestion.

- A, A, A.** Sublobular-hepatic veins, terminating in
- B.** An hepatic trunk. No intralobular veins terminate in this vein; its coats are not transparent; the hepatic-venous canal containing it is lined by a prolongation of the proper capsule.
- C.** The capsular surfaces of the lobules forming the canal, in which the venous trunk is contained. The veins of these lobules terminate in a neighbouring sublobular vein.

- D, D. The parietes of the hepatic-venous canals, a portion of the vein having been removed.
- E, E. The orifices of the intralobular veins, which enter the sublobular veins from the centres of the bases of the lobules forming the parietes of the canal containing the veins. Each orifice is situated in the centre of the congested portion (the red substance of FERREIN) of each lobule.
- F. Longitudinal sections of lobules, the intralobular veins of which are seen terminating in the sublobular vein.
- G. The orifices of intralobular veins less closely arranged than at E, E.
- H. The capsular surfaces of lobules, which, with the bases of other lobules, form these canals.
- I. The parietes of the canal containing this vein are formed by the bases alone of lobules.

Fig. 3. A. An hepatic duct.

B, B. The transverse branches of the duct.

C, C. Branches which ramify in the direction of the trunk.

D, D. Recurrent branches.

E. Smaller branches arising at the angles formed by the preceding branches.

Fig. 4. A longitudinal section of a portal canal, with an hepatic duct and its vaginal branches ramifying on the parietes of the canal. The lobules are angular and in a state of anæmia.

A, B, C, D, E. As in the preceding figure.

f. A vaginal duct leaving the canal and dividing into interlobular branches.

G, G. Ducts entering smaller portal canals.

PLATE XXIII.

Fig. 1. Represents the internal surface of a small hepatic duct, with its follicles arranged in two longitudinal lines.

Fig. 2. An hepatic vein of the *Seal* laid open, and showing the circular fibres of which its external coat is composed.

Fig. 3. Represents the interlobular ducts entering the lobules, and forming the lobular biliary plexuses.

- a.* Two lobules.
- b, b, b.* Interlobular ducts.
- c, c, c.* The interlobular cellular tissue.
- d, d.* The external portions of the lobular biliary plexuses injected.
- e, e.* The intralobular branches of the hepatic vein.
- f, f.* The uninjected central portions of the lobules.

No such view of the ducts as that represented in this figure can be obtained in the liver. The interlobular ducts are, in the figure, seen anastomosing with each other: I have never seen these anastomoses, but I have seen the anastomoses of the ducts in the left lateral ligament, and, from the results of experiments related in this paper, I believe the interlobular ducts anastomose. I have never injected the lobular biliary plexuses to the extent represented in the figure.

Fig. 4. Represents the biliary ducts ramifying in the left lateral ligament of the liver.

- a.* The left lateral ligament of the liver.
- b.* The posterior edge of the left lobe of the liver.
- c.* The loose edge of the ligament.
- d.* That edge of the ligament which is connected to the diaphragm.
- e, e.* Biliary ducts emerging from the liver and ascending to ramify in the ligament.
- f.* Arches formed by the ducts towards the upper part of the ligament.
- g.* The plexuses formed by the minute ducts.

Fig. 5. Representing the interlobular branches of the portal vein, the lobular venous plexuses, and the intralobular branches of the hepatic veins of three lobules.

- a, a, a.* The interlobular veins contained in the spaces.
- b, b, b.* The interlobular veins which occupy the fissures, and which, with the veins in the spaces, form venous circles around the lobules. This is the appearance which the venous circles present when

examined with a common magnifying glass ; they are, however, formed by numerous, and not by single, branches, as represented in the figure.

c, c, c. The lobular venous plexuses, the branches of which, communicating with each other by intermediate vessels, terminate in the intralobular veins. The circular and ovoid spaces, seen between the branches of the plexuses, are occupied by portions of the biliary plexuses, constituting the acini of MALPIGHI.

d, d, d. The intralobular branches of the hepatic veins, in which the vessels of the plexuses terminate.

Fig. 6. A transverse section of a portal canal, showing the relative dimensions of the vessels in the liver of the child, in which the portal vein terminated in the inferior cava.

- a.* The umbilical, or hepatic-portal vein.
- b.* Three arteries contained in the same canal.
- c.* The duct.
- a.* An hepatic vein.

XXX. *Some Observations on the Economy of Molluscou Animals, and on the Structure of their Shells.* By JOHN EDWARD GRAY, Esq., F.R.S., &c.

Received June 8,—Read June 13, 1833.

1. *First Formation of Shells.*

THE shells of Mollusca appear to be coeval with the first formation of the animal: they may be observed covering the embryo on its first development in the egg, even before it has acquired its proper shape or any of its internal organs. The accurate SWAMMERDAM observed them in the eggs of several of the garden and pond snails. His observations have been recently verified and extended by PFEIFFER, on many species of land and fresh-water Mollusca; and I have myself observed the same fact in the eggs of several animals belonging to the different orders of marine shells: there is reason, therefore, to believe that this circumstance is general throughout the class. These observations are most easily made on the embryo of the fresh-water shells, such as the *Lymnææ*, *Physæ*, *Ancyli*, and *Bithyniæ*, the eggs of these animals being covered with a transparent coat; while the viviparous Mollusca, and especially the *Littorinæ*, *Paludinæ*, and *Cyclades**, offer the additional advantage of exhibiting the embryos of their animals in all the different states of development at the same time.

The cephalopodous Mollusca form no exception; their bone, composed of

* Between the laminæ of the branchiæ of the *Anodontes* and *Uniones* are found small cordate, bivalve bodies, which have been considered as their young; but they differ so much in external form and internal structure from the adults, that many excellent naturalists, and especially Professor JACOBSON, of Copenhagen, have considered them as parasites. It is, however, remarkable that they are found in abundance in almost every specimen, and PFEIFFER has apparently proved that they are the young, he having found them constituting the umbones of very minute *Uniones*. I have searched for them in vain in this situation; perhaps because I have never been so fortunate as to discover specimens of the young shell so small as those figured by this author. If PFEIFFER should prove to be correct, this remarkable change of form and structure will be the only approach towards a metamorphosis that has been hitherto observed in this class of animals.

two or three calcareous plates, being found fully developed in the egg of the Cuttle-fish some time before the young animal is hatched.

These observations are directly at variance with the theory maintained by the late Sir EVERARD HOME*, viz., that the shell of the Vermes Testacea is formed after the animal has quitted the egg; and as regards the Cuttle-fish, they are opposed to the remark, made by the Baron CUVIER, that the young Cuttle-fish, when first hatched, has only a cartilaginous plate like the *Loligo*.

The shell when first observed on the embryo (even of the animals of spiral shells) forms a short, blunt, more or less curved, subcylindrical cone, covering the hinder part of its body: as the organization of the embryo becomes developed, and the hinder part of the body extended, the shell increases in size, till the body and shell together occupy nearly the whole of the egg. While inclosed in the egg, the embryo shells are generally of a pale horn colour, and destitute of markings: when, therefore, they remain attached to the apex of the spire of adult shells, they may be easily distinguished by their appearance from the part formed after their exclusion; and as, in such cases, they offer some characters of importance, it has been proposed to designate them by the name of the Nucleus of the shell.

The effect of the atmosphere on the shell is almost instantaneous: in some young *Helices* and in a species of *Voluta* in my collection, the very first line of calcareous matter deposited after their exclusion from the egg is marked nearly as the adult shells of the species.

The nucleus may be generally distinguished from the perfect shell, by the rapid enlargement of its whorls, by its extreme tenuity, by its want of colour, and by the great obtuseness of that part which is earliest formed and constitutes the extremity of its first volution. It is necessary to pay attention to these particulars, inasmuch as the nuclei of some large species have been mistaken for full-grown shells, and vice versâ. Thus the *Murex decollatus* of PENNANT is the just-hatched shell of the *Fusus despectus*; Risso's genus *Orbitalina* is established on the nuclei of two land shells; and the genus *Vitrina* was regarded by MONTAGU as the nucleus of the Common Snail. In some instances the first half-whorl of the nucleus, (the part first formed on the embryo,) instead of being regularly curved, is bent across the tip of the other

* Philosophical Transactions, 1817, p. 229.

whorls, as in the *Pyramidellæ*, or placed in an oblique position with regard to the succeeding one, as in *Voluta papillosa* and some other species.

The nuclei of many shells of different genera have not the same characters as their parent shells; thus the nucleus of the Tritons has a short anterior nick, instead of an elongated canal, and is very like a minute Buccinum. Some retain the generic but not the specific character of the group to which they belong; thus the nuclei of the Volutes in general have the pillar slightly plaited, but the young of *Voluta musica* has only two or three plaits on its pillar, while the adult has many.

The nucleus forms the original apex of the valves of all shells whatever may be their form, and frequently remains attached to them during all their periods of growth; this is particularly the case with the Volutes, in which, from its large size and rounded shape, it has been called the Nipple. It is also conspicuous on most of the species of *Dolium* and on some *Fusi*, among the univalves; and on the apices of the valves of the *Cyclades*, and *Chamæ*, among the bivalves.

This part of the shell has not received the attention that it deserves. It is largest in those shells the animals of which are viviparous; and is consequently very distinct in the *Volutæ*, *Paludinæ* and *Cyclades*. In the oviparous species it agrees in size with the egg of the animal; thus *Achatina octona*, which has an egg nearly equal in dimensions to the mouth of the shell, and *Bulinus ovatus* and *B. bicarinatus*, which have large eggs, have large nuclei, the magnitude of the nucleus in general rendering the top of the spire blunt. Some shells on the contrary, those, for instance, of the genus *Stylina* generally, and of the *Pupa purpurea*, have a very long, slender, acute, turreted nucleus, but the form and size of the eggs are in these cases unknown.

The nucleus is found on examination to consist of two very distinct parts or coats, the outer of which is membranaceous or horny, and called the Periostracum, and the inner hard and calcareous, and constitutes the Shell.

These two coats may be observed in all the stages of the shell: they are generally very thin in the nucleus, and the outer one is rarely distinctly visible in that state; but it is to be clearly seen (covered with five or more bands of hair-like processes) in the very young *Paludinæ*. In such shells as are enveloped in the mantles of their animals, as the *Dolabellæ*, *Aplysiæ* and *Bullææ*, the outer coat or periostracum is very thin; it is, however, to be found in all shells,

and may also be observed on the shelly plates of the Cirrhipedes. In some instances, as in the Cowries and Melons, the outer coat of the shell is covered in the adult age with a deposition of shelly matter, which entirely conceals it from view. A few shells, as for example those of *Loligo* and *Aplysia*, contain so little calcareous matter, as to appear to be formed entirely of periostracum.

2. *The external Form of Shells, and their Variations.*

Each valve of a shell, according to the manner in which it is first formed and subsequently increases, is a more or less depressed or lengthened cone. The apex of this cone is always oblique: in all the shells with which I am acquainted, it is excentric; and in most of the univalve shells, whether they be simply conical, involute or spiral, it is directed from the head of the animal towards the hinder part. The only exception, as far as I know, to this rule, occurs in the genera *Patella* and *Lottia*, in which the apex is directed from the hinder part towards the head; and this is the more remarkable, as in the Chitons, the animal of which so much resembles that of *Patella*, each of the valves takes the usual direction. The similarity of direction in the two genera above named is still more curious, as their animals bear scarcely any resemblance to each other.

The nucleus of the bone of the Cuttle-fish and of the *Loligo*, is placed in the same direction; for it is the conical process at the end of the bone of the Cuttle-fish (called *Beloptera*, when found in the fossil state,) which must be regarded as the nucleus of these shells. If, however, the relative position of the animal of the Nautilus, the anatomy of which has been admirably described by Mr. OWEN, be correctly assigned by that author, with respect to its shell, it must offer a similar anomaly with the genera *Patella* and *Lottia*. The shells of the Pteropodes, as for example *Hyalæa*, *Cleodora* and *Vaginella*, take the same direction as the other univalves; and it was this circumstance that gave rise to the supposition that M. DE BLAINVILLE, in his figure of the animal of *Cymbulia*, had placed it in the shell in the wrong position. The numerous specimens which are now in European cabinets have proved the accuracy of this supposition.

In bivalve shells the apex of each valve is always placed on or near the dorsal or hinge margin, varying its position on this part in the different groups.

Thus, in the *Pectines* and other suborbicular shells, which having a very large subcentral posterior adductor muscle, were called by LAMARCK *Monomyaires*, the apex is generally in or near the centre; while in most of the other genera it is placed more or less towards the anterior extremity of this margin, and is sometimes incurved. In some of these shells the apex is spirally twisted, and the spire becomes more developed as they increase in size. Now this could not take place if the valves remained inseparably united together at the same part of the dorsal margin; but it is provided for by the hinge of the shell being gradually moved backwards on the edge of the valves, the ligament separating in front of the hinge into two parts, one of which diverges along each of the umbones, and forms a spiral groove down the suture of the whorls. In *Isocardia* the umbones seldom make more than half a turn, but in one specimen of *Chama* in my collection they have made an entire revolution, and in another a revolution and a half. The valves of these shells being unequal, the spiral part of the lower or attached valve is produced into an elongated cone, while in the other it is depressed, and simply marked with a spiral groove, like that of an operculum.

In most bivalves the hinge margin, which is deposited by a part of the mantle extended behind and between the teeth, increases in size much more slowly than the other margins of the shell; but in some free shells, such as the *Arcae*, this part increases nearly as rapidly as the rest, and the umbones thus become separated from each other by a lozenge-shaped disk. In others which attach themselves to foreign bodies, as the *Spondyli* and *Ostreæ*, the hinge margin of the attached valve only enlarges, forming a triangular flat-topped process, while that of the upper valve is scarcely increased in size. Thus the cavity of the shell, as the growth proceeds, gradually retreats from the part by which the attachment first took place.

The direction followed by the whorls in passing down the axis derives its origin from that which the shell takes in the egg; and is probably dependent upon the direction in which the embryo rotated whilst inclosed therein. In most shells they turn from left to right, and the mouth is on the right side of the axis, when the shell is in its natural position; but in others, which are called sinistral or reversed, the whorls are twisted in the contrary direction. The sinistral direction appears to be constant in many species, especially

among the air-breathing Mollusca ; in all belonging to the genus *Clausilia*, among the land ones ; and in all the *Physæ*, *Planorbes* and *Ancyli*, among those which inhabit fresh water. But besides these entire genera, the shells of which are invariably sinistral, there are numerous species of *Bulimus*, *Partula*, *Pupa*, and *Chondrus*, that are uniformly so twisted ; and there are even some that are sometimes twisted in one direction and sometimes in the other, as *Bulimus Lyonettianus*, *B. aureus*, &c. Among the marine shells the sinistral direction is much more rare, although there are a few species, such as *Fusus sinistrorsus* of DESHAYES, *F. contrarius* and *F. sinistratus* of LAMARCK, and some species of *Cerithia*, which are constantly so contorted. The *Pyrula perversa* is as often found twisted in one direction as in the other, and its shells have even been considered as different species according to the direction of their whorls. Of other marine species liable to the same variation, I have observed *Buccinum undatum*, which is not uncommonly found reversed ; *Turbinella napus*, the reversed variety of which is much sought after by the Chinese ; *Oliva oryza*, *Nassa reticulata* and *N. Thersites* ; but there are some genera in which I do not recollect to have noticed its occurrence, as, for example, the *Cyprææ* and *Ovulæ*.

A bivalve shell is composed of a dextral and a sinistral valve, united together by a ligament. When the two valves are separated, and spread out on a table with the umbones above, and the front end towards the observer, the valve to the right (the left when on the animal and in its usual walking position,) resembles a dextral, and that to the left a sinistral, very depressed spiral shell. This is well illustrated by comparing the left valve of an *Isocardia* with a *Concholepas*. In some very rare instances these shells also are reversed, but the fact is not easily observed, except in the unequal-valved kinds. There were formerly in the TANKERVILLE collection two specimens of *Lucina Childreni*, in one of which the right valve was a dextral shell, in opposition to the general structure. A much more remarkable variation is to be observed in some of those bivalve shells, whose under valve is attached to foreign bodies ; thus, for example, most of the *Chamæ* are attached by their left valve, but some species, such as *Chama Lazarus*, are frequently attached by their right valve, under which circumstance the teeth proper to the left and usually attached valve are transferred to the right, and vice versâ.

The equality or inequality of the valves of bivalves appears to be dependent on the habitual position of the animal. Thus all the genera whose animals bore perpendicular holes in rocks, like the *Pholades*; or bury themselves in the mud of rivers, as the *Uniones*; or in the sand of the sea-coast, as the *Cardia*; or walk freely about on the shores, as the *Veneres*; or are attached by a byssus which passes out of a gape formed by the inflection of the margins of both valves, as the *Tridacnæ*, *Saxicavæ* and some *Arcæ*, have equivalve shells: whilst on the other hand, all those Mollusca whose shells are immediately attached by the outside of one of their valves, as the *Etheriæ*, *Ostreæ*, *Spondyli*, *Hinnites* and *Chamæ*; or of which the animals are attached by a byssus passing through a groove near the umbo of one of the valves only, as the *Pectines*, *Aviculæ*, *Peda* and *Anomiæ*; or which lie free on the surface of one of their valves, as the *Ostreæ*, *Anatinæ*, and some of the *Arcæ*, are more or less inequivalve. In those inequivalve shells which are attached by the intervention of a byssus, this substance passes out through a groove in the right valve, which is the smallest; whilst, on the other hand, in those that are immediately attached by the outside of the shell, the right valve is affixed, and the left is the smallest, sometimes indeed so disproportionately as to appear like a lid to the other. It is only in the families *Ostreidæ* and *Anatinidæ*, which have unequal valves, that there are found some genera entirely free, and others which are immediately attached. The free inequivalve shells offer some curious anomalies in the relative size of their valves; nearly all the *Anatinidæ*, as *Anatina*, *Periploma* and *Magdala*, having the left valve the smaller, as have also the genera *Corbula* and *Sphaenia* of the family *Myidæ*; whilst the other two genera of that family, *Mya* and *Pandora*, and *Lyonia* among the *Anatinidæ*, have the right valve the smallest.

In the *Terebratulæ* and Brachiopodous Mollusca in general, the valves being applied to the dorsal and ventral, instead of the lateral, surfaces of the animal, their lateral halves are analogous in situation to the right and left valves of other bivalves, and the byssus by which the animals are attached passing through a hole in the centre of the dorsal valve, the sides of the shell are equal. The dorsal or perforated valve is superior and convex in all the genera of this order, with the exception of *Discina*, in which, the usual position of the animal being reversed, it is inferior and flattened.

In all shells, the young of which I have had an opportunity of observing, the nucleus or shell of the animal when first hatched is regular. The irregularity in the form of adult shells appears to depend on their becoming attached to foreign substances, for it is only among attached shells that any irregularity of form is found, and even these are perfectly regular so long as they continue free. This explains why irregular shells are more rare among the univalves than among the bivalves, as not more than three or four genera of the former ever become attached. Good examples of shells which are irregular when full grown, although regular in their very young state, may be seen in the genera *Ostrea*, *Chama*, *Hinnites*, *Magilus*, and *Vermetus*. The very young shell of *Chama arcinella*, which closely resembles in form a minute *Petricola*, is frequently found persistent and constituting the apex of the umbones of adult specimens; and so regular is its form, that I have little doubt, were a conchologist to meet with a very young free specimen among the sand of the West Indian coasts, that he would refer it either to the latter genus, or to the genus *Cardita*. In like manner the very young shell of *Hinnites pusio*, when persistent in the umbones of the adult, cannot be distinguished from a free regular *Pecten*.

Many univalves exhibit the same phenomenon: the young *Spiroglyphus* and *Magilus*, as will hereafter be described, are quite regular so long as they remain free; and the apices of all the *Vermeti* and *Siliquariæ* show that they also are regular in their youth. The apex of the former has indeed been mistaken for a regular spiral shell, and described as a *Turritella* by LAMARCK and by Dr. TURTON.

Some land shells (for it is only in such shells that I have observed it,) offer a very curious anomaly in their form: they are quite regular in their young state, but change the direction of their last whorls as they approach maturity, and in some cases even reverse the position of the mouth. A remarkable instance of this change of direction occurs in a rather common Brazilian snail, which is transversely striated in its young state, and exactly resembles a common umbilicated snail; but acquires when adult a smooth last whorl much larger than the others, and pressed towards the side next the mouth, by which means the axis is bent out of the line, and the umbilicus is compressed and closed. This obliquity in the form of its whorls gives the shell the

appearance of having been slightly crushed, from which circumstance it has been called by Baron FÉRUSAC *Helix contusa*. A similar departure from the regular form is found, in even a greater degree of development, in a minute species from the same country, named *Helix deformis* (Wood's Supplement, tab. 7. fig. 40.); and may also be seen in a slight degree in the *Helix concamerata* of Wood's Supplement, tab. 7. fig. 21. The last whorl of *Bulimus Lyonettianus* is compressed on the side opposite to the mouth, and produced into an acute angle, which gives the shell a very anomalous appearance. A somewhat analogous deformity, but not so much developed, may also be observed in *Helix Auris Leporis*. This kind of variation is, however, not confined to the inoperculated land shells, for the *Cyclostoma compressum*, figured by Mr. Wood in his Supplement, tab. 6. fig. 42, differs from all others of the genus in its last whorl being compressed, although not in so great a degree as in the *Bulimus Lyonettianus*; and in the *Cyclostoma tortum* (*Turbo tortus* of Wood's Supplement, tab. 6. fig. 32.) the last whorl is slightly pressed on one side like that of *Helix contusa*, the mouth being produced in front, and nearly in a line with the axis.

But the most remarkable of these anomalies occurs in the genus *Anastomus*, where the mouth of the young shell occupies its ordinary situation in front of the whorls, the animal in this early stage doubtless crawling in the usual manner, with the spire of the shell uppermost; but as it approaches maturity, the end of the last whorl is curved upwards, and the mouth of the perfect shell is applied to the upper edge of the last whorl but one, with the opening directed towards the tip of the spire, in such a manner that, in walking, the animal must crawl with the tip of the spire downwards, and thus completely reverse the position of its shell. A similarly formed shell has been discovered in the fossil state, and named *Strophostoma*, and this, from the roundness of its mouth, has been supposed to belong to the family of *Cyclostomidae*.

The axis of most spiral shells is perfectly straight, but the species of some few genera, such as *Eulima* and *Stylifer*, are very liable to have it more or less curved or twisted. And this is not the only point of resemblance between these two genera, both having the same polished surface and similar varices on the spire; but they differ in the degree of solidity of their shells. The *Styliferi* live buried in the substance of Star-fish, which may perhaps account for their inflections: the habits of the *Eulimæ* are unknown.

The growth of other spiral univalve shells appears never to be thrown out of its proper course, except by some accident, such as the interruption caused by the occasional attachment of a foreign body, or by a fracture. I have a *Fusus virgo* and a *F. colosseus*, which are thus bent; and there are two specimens of the common Whelk in the British Museum, the spires of which are very much elongated, the elongation having evidently been caused by a fracture in their very young state. One of the latter has been described as a distinct species, under the name of *Buccinum acuminatum*. Sometimes, after the occurrence of such an accident to a spiral shell, the form or sculpture of the whorls is entirely altered: they often become ventricose and smooth, instead of remaining thick and ribbed, as in the common state of the shell; and this change of form has even occasioned shells under such circumstances to be regarded as distinct species. As an instance of this I may refer to *Cingula alba* of Dr. FLEMING, founded on specimens of *Turbo parvus* of MONTAGU, which had been injured in their growth. In Mr. TURNER's collection there is a specimen of *Terebra maculata*, which had sustained an injury when about an inch and a half in length: the whorls beyond this injury are rounded and elevated near the suture, and are destitute of the posterior groove. In this specimen the colouring also is altered, for instead of being spotted, the irregular volutions are marked only with two narrow posterior spiral bands.

A distortion or change of form, caused by a fracture or other accident, is sometimes overcome, as the animal increases in size and recovers its strength. Thus a specimen of *Strombus bituberculatus* in my collection, which had met with an accident in its young state, has the five upper whorls sharply keeled and nodulous, as in the ordinary state of the shell, but the volutions formed after the accident turn more obliquely down the axis, and thus their anterior part becomes more exposed, leaving a deep narrow groove on the suture. The first half-whorl that succeeds the fracture is rounded and distinctly tubercular; after which the shell continues rounded, but quite smooth for a whorl and a half; when it again becomes slightly tubercular, and at length keeled and tubercular, the last whorl exactly resembling the last whorl of the normal shell. The collection of Mr. LINCOLNE of Highbury contains a specimen of *Cassis rufa* in a very similar state.

The shape of attached shells depends greatly on the form of the bodies to

which they are applied ; and this is a circumstance that has been generally overlooked by conchologists. It strongly affects most shells that are immediately and permanently attached, such as the *Chamæ* and *Ostreæ*, which completely assume the form of the substances on which they grow. Thus the *Chamæ* and *Spondyli* attached to the plane surface of mother-of-pearl shells have always a flat side, whilst those which are adherent to coral and to other uneven surfaces are variously and irregularly shaped. The Oysters which are attached to the branches of mangrove trees have a central convex rib, modelled on the shape of the branch, from which the plaits of the shell radiate ; while the specimens of the same species fixed to the trunk are destitute of any such peculiarity. In the collection of Mr. ADAMSON of Newcastle there is a curious specimen of a common Oyster found in the Frith of Forth attached to a species of *Pecten* ; on the latter there also grew three corallines, surrounding the Oyster, which have formed in its circumference three deep notches, giving it the form of an ace of clubs. The same changes may be observed to take place in the *Anomiæ*, which are attached by the intervention of a ligamentous band ; thus the species called *Anomia squamula* is founded on young shells of the common *A. ephippium* attached to flat surfaces ; whilst *A. cymbiformis* is characterized from small specimens of the same shell attached to the cylindrical spines of sea eggs, or to the stems of sea weeds.

A similar influence is also observable in such free univalve shells as have a widely expanded mouth, and an animal provided with a large foot, by means of which they remain for a considerable length of time adherent in the same situation. When a *Patella* or a *Crepidula* has attached itself to the flat surface of a rock or the leaf of a large *Fucus*, the base of its shell is flat, and its mouth roundish ; when it adheres to a concave surface, such as the cavity of an old shell, the base becomes flattened, and convex internally ; and when it fixes itself on the rounded stalk of a *Fucus*, the sides become compressed so as in some measure to clasp the stem, and the lateral portions of the base project beyond the front and hinder parts, to such an extent that when placed on a flat surface it rocks backwards and forwards. Several nominal species of these and allied genera depend on variations in the shape of the shell caused by the adhesion of the animal to surfaces of different forms ; thus the *Patella pellucida* of MONTAGU is synonymous with the *P. cærulea* of the same author, the former having

been founded on specimens taken from the stalk, and the latter on individuals obtained from the flattened frond of the *Fucus* on which the species usually takes up its abode: it is indeed by no means rare to find specimens in which the animal has moved from one of these positions to the other, and in such cases the apex of the shell represents *P. cærulea* and the base *P. pellucida*, or vice versâ. The same change takes place with regard to *P. miniata* and *P. compressa*. I have in my collection a specimen of this latter shell which is *P. miniata* at the top, it having in its youth lived on the frond of a large Cape *Fucus*: it afterwards removed to the stem, and became compressed, and consequently is in this part the *P. compressa*; but by some accident it was again induced to change its situation, and, removing to a flat surface, the edge of the mouth expanded, and it became a second time *P. miniata*, or perhaps what may be called by some authors *P. saccharina*, as this also appears to be a conical variety of the same species. LAMARCK has described a similar specimen; and Mr. SOWERBY, in his Genera of Shells, has figured an example of this species, showing the two states. In like manner the *Crepidula porcellana*, when applied to a flat surface, has an expanded base and a flattened inner lip; but when adherent to a convex body, such as the stem of a sea-weed, or (as frequently happens) to the back of another shell of the same species, the animal being pressed into the cavity, the inner lip becomes concave, and the sides of the aperture are contracted: in this state the shell is called by most authors *C. fornicata*.

When the shells of this family are adherent to irregular surfaces, they adapt their margins to the inequalities with which they meet. I have several specimens from the coast of Devonshire, having one or more processes on their sides, which fitted into holes in the rock to which I found them attached; and such changes are the more remarkable, as some specimens are seen constantly moving from place to place, whilst others appear to remain for a long time fixed in one spot, and even those that are thus stationary in the young state constantly elevate the margins of their shells when the tide is low. I have also a specimen of *Siphonaria gigas* exhibiting in a great degree a similar adaptation of its edges to the form of the rock on which it grew.

The substances to which attached shells become adherent, besides altering their general form, often change the character of their surfaces; thus, when fixed to ribbed shells, like the *Pectines*, *Cardia*, &c., they are frequently

variously ribbed, a circumstance which often takes place in the common *Anomia*; and if attached to a *Dolium*, as in a specimen in the collection belonging to Mrs. MAUGER, they even exhibit on their own surface the alternate broad and narrow ribs of that shell. In specimens of *Crepidula adunca* attached to *Trochus doliarius*, (and inhabiting the same locality, they are not unfrequently so attached,) the convex part of the former is marked with the ribs of the latter. Shells which are ribbed from this cause are, however, easily distinguishable from those which are naturally ribbed, the ribs in the former generally extending across or along the shell, and not radiating from its apex or nucleus, as in all shells the natural character of which is to be ribbed. In those which adhere to ribbed shells by the foot of their animal (as in most of the univalves), and are therefore capable of being moved from place to place, the young animal may have lived on a smooth surface, and have had a smooth shell; and may have moved, during its growth, to a ribbed body, producing ribs on the later formed part of its shell, or vice versâ. In a specimen of *Crepidula adunca*, for example, in the British Museum, the upper half of the shell is smooth, and the lower half ribbed; and I have seen specimens, on the contrary, in which the apex was ribbed and the base smooth.. This change of form has, however, misled some conchologists, for Dr. BRONN, of Heidelberg, has founded a genus under the name of *Brocchia*, on a specimen of *Capulus*, which had acquired a ribbed surface in consequence of having been attached to a *Pecten* or to some other radiated shell.

These alterations of form and surface are always most distinct in univalves and in the upper valve of bivalves. In the latter case, the edges of the upper valve being produced beyond those of the under, they are immediately moulded on the surface of the substance to which the shell is attached, whilst the under valve simply covers it over. This is well illustrated in the unique specimen of *Hinnites gigantea* in the collection of the British Museum, which must have been attached to some marine body having a *Serpula* growing upon it. There is merely an irregular convexity in the inner part of the under valve, but on the outer surface of the free valve is to be observed a representation of the whole form, and of almost the entire surface of the *Serpula*, in consequence of the edge of that valve, during each deposition of shelly matter, having rested on the worm-shell. In the collection of Mr. LINCOLN is a specimen of an

Oyster which, having been attached to a plank covered by a number of *Balani* and *Serpulæ*, has the upper valve marked with prominences, exactly agreeing in shape with the substances concealed beneath the under one. The edges of the valves of Barnacles being very closely affixed to the surface of the substances to which they are attached, it appears that they not only assume the form of the larger prominences, such as the ribs and spines of a shell, but also the most minute differences of its surface. A Barnacle in my collection, which had been fixed to a Scollop (*Pecten suborbicularis*), has not only the ribs of the latter marked across its valves, but the whole surface of the prominent part of the valves is covered in addition with minute rugosities, produced by the small projecting scales which cover the surface of the ribs of the *Pecten*, whilst the articulating portion of the valves is smooth, as in the common state of the species. In another similarly ribbed specimen the articulating portions are also ribbed like the rest of the valves; and in a third, which was found on a piece of roughly planed and loosely textured wood, the surface of the valves bears an exact resemblance to the grain of the wood on which the specimen was attached.

The thickness, the roughness, and the smoothness of the surfaces of shells appear to depend, in a great measure, on the stillness or agitated state of the water which they inhabit. The species of our own coast afford abundant instances of this: the shells of *Buccinum undatum* and *B. striatum* of PENNANT have no other difference than that the one has been formed in rough water, and is consequently thick, solid and heavy; and the other in the still water of harbours, where it becomes light, smooth, and often coloured. In the same way the specimens of *Purpura Lapillus*, which inhabit sheltered situations, are covered with small arched scales, whilst those found in exposed places are thick and rugose. LAMARCK, not being aware of this circumstance, considered the specimens in the first state as a distinct species, which he named *Purpura imbricata*. The English shells of the genus *Pinna* (and doubtless the foreign ones also,) offer the same variations, which have given rise to similar subdivisions of species. Shells which have branching or expanded varices, like the *Murices*, are also much influenced by these circumstances; and hence many mere varieties, arising from local causes, have been considered as distinct species. Thus *Murex angulifer* is merely a *Murex ramosus* with

simple varices; and *Murex erinaceus*, *M. torosus*, *M. subcarinatus*, *M. cinguliferus*, *M. Tarentinus* and *M. polygonus*, are all varieties of one species. *Murex Magellanicus*, when found in smooth water, is covered with large acute foliaceous expansions; but the same shell living in rough seas is without any such expansions, and only cancellately ribbed. In such situations it seldom grows to a large size; but when it does so, it becomes very solid, and loses almost all appearance of cancellation. *Triton maculosus* is very widely spread over the ocean in different temperatures and different kinds of seas; it consequently offers a multitude of varieties both in size and surface, all gradually passing into each other, and most probably produced by the operation of the foregoing causes. Indeed, a vast number of merely nominal species have been formed from the habit, too prevalent among conchologists, of describing from single specimens, or even from several individuals brought from the same locality, which would never have been considered as distinct had collectors kept in their cabinets a series of specimens found under different circumstances, and studied, on the coasts where they are found, the variations which shells undergo.

Those shells which are attached to rocks, either immediately by their outer surface, or by the intervention of a beard, are most acted on by these causes: thus the *Anomiæ* found in protected places are thin and transparent, while those which inhabit exposed situations are thick and nearly as opaque as the shell of an oyster; and the under valves of the *Cranie* which are affixed to the branches of coral are very thick and solid, while those that adhere to the *Pinnæ* and other flat shells are so thin as to have been overlooked by conchologists, who have repeatedly described their upper valve as a species of *Patella*.

Boring shells are greatly influenced in regard to their size, thickness and form by the hardness or softness of the rock in which they are found: thus the specimens of *Pholas dactylus* found in the soft rock of Salcombe, are large and thin, and are covered with beautiful, regular, arched scales; while those found in the hard rock are small, irregular, thick, with a very wide anterior gape and large dorsal valves, and closely wrinkled externally, but almost or entirely destitute of scales: and the *Saxicavæ*, found in hard limestone, are often curved and otherwise distorted, in order to avoid the harder parts of the rock during the process of boring.

Land shells are much influenced, as regards their size, by the temperature, altitude, and abundance of food, of the country in which they are found. Specimens of *Helix arbustorum* from the Swiss Alps, are not one half the size of those of the neighbourhood of London; the shells of *Helix nemoralis* and *H. hortensis*, found in the last-named locality, are not above two thirds the size of those which occur in Portugal and in the South of France; and there is so much difference in size between individuals of *Bulimus rosaceus* found on the coast and on the mountains of Chili, that the latter have been described as a distinct species under the name of *Bulimus Chilensis*. There would be no difficulty in multiplying examples of the same kind.

It is not so easy to determine the influence of climate on marine shells, although there is little doubt, from the great differences of size observable between specimens of the same species, brought from different localities, that it actually exerts considerable power. Indeed, I have been enabled to mark this difference in some of the shells found on our own coast. The specimens of *Littorina petraea* found on rocks with a southern exposure near Torquay, are larger than almost any others which I have met with in England; but the largest of this species that I have seen, occur on the part of the Breakwater at Plymouth next the sea, where they are much exposed to the sun. The latter are twice the size of any that I found on the northern face of that magnificent structure.

The colouring of many shells evidently depends on the degree of exposure to light, air, heat, and the action of the waves to which they may have been subjected. Thus, among the *Patellæ* and *Crepidulæ*, those which are attached to the stems of *Fuci* or other round bodies, and are thus exposed on all sides, are of a dull colour, or nearly colourless. This is well exhibited in the specimen of *Patella miniata* before referred to, which had changed its place of attachment twice during its growth; the two portions of the shell formed while the animal was affixed to a flat substance being white, beautifully varied with bright red, (the general colour of *P. miniata*), whilst the central portion of the shell is of a dirty yellow, with a few indistinct, reddish dots, like the ordinary specimens of *P. compressa* *. In like manner *P. pellucida* when obtained from the stems

* Such exposed shells are very rarely brightly coloured; but a specimen of *Patella compressa* formerly in the collection of the late Earl of Tankerville, but now in that of Mr. Lincoln, is coloured nearly as brightly as *P. miniata*.

of *Fuci* is of a pale horn colour, whilst the same shell, on the leaves, is of a beautiful purple with longitudinal pale blue lines. The thinnest specimens of a species are generally the best coloured. The light certainly exerts considerable influence on the strength of colour, even in marine shells; and it appears to be owing to its modifying power that many *Nassæ*, *Buccina*, *Naticæ*, *Cyprææ*, and other littoral shells, have the back part much darker than the rest. This is particularly the case with *Nassa glans*, *Natica castanea*, and several Cowries, as *Cypræa stolidæ*, *C. errones*, and *C. caurica*, which have always an irregular bright red spot on the back of the body volution.

The colour of shells is generally disposed in rays, streaks, or bands, arising from the nucleus and extending to the circumference; in the spiral shells the lines of colouring consequently follow the direction of the whorls. The rays vary greatly in size; they are sometimes interrupted, and they generally become wider as the shell grows larger.

These coloured bands are evidently deposited by glands placed on the margin of the mantle. Sometimes the action of the glands is interrupted, and the bands are broken. In a few shells this suspension of the action of the glands takes place at regular and very short intervals, in which case there is formed a chain-like band, as in *Marginella catenata*, certain Cones, and some other shells. In the *Volutæ*, *Olivæ*, *Coni* and some *Cassides*, the colouring often forms angular lines, so disposed, that the glands which deposit it seem to have receded from each other, and then again contracted together. Sometimes, as in *Olivæ tessellata*, for example, these lines are broken into spots; but even in this species some specimens exhibit the spots united into angular lines.

In general the colour is situated on the outer coat of the shell. It is often deposited on the inner side of the outer layer, as in *Strombus bituberculatus*, and sometimes extends a little into the outer part of the middle layer; but I do not recollect to have ever seen it pervade the whole thickness of this coat. This circumstance leads me to believe that the colouring matter is generally deposited by the glands immediately after the deposition of the calcareous particles on the periostracum, and during the formation of the outer coat which, as will be seen hereafter, is always deposited before the two inner ones.

This situation of the colouring matter explains the reason why many shells,

such as the Olives and Cones, are darker when their outer coat is removed; as is particularly the case with *Oliva utriculus*, which is often sold in that state as a different shell. There is reason to believe that LAMARCK was deceived by a specimen which had been so mutilated, and which he described as a distinct species, under the name of *O. harpiformis*.

The belts across the whorls of the *Olivæ* and *Ancillariæ* have the coloured matter deposited on their inner surface. In a few shells, the *Oliva porphyria* for example, some of the more distinct coloured lines even form raised ridges on the outer surface; and in some others the inner layer is darker than the outer. Thus in *Oliva tessellata* and *O. lineolata*, and in some Cowries, the inner layer is purple; in *O. ispidula*, brown; in *Turbo chrysostomus* and *T. Nicobaricus*, bright golden; in *Capulus Hungaricus*, in *Strombus gigas*, and in many others, pink: but it is generally much paler, and in the greater number of shells white or colourless.

Some brown shells, such as the Volutes, become white when touched with a hot iron: there was formerly in the Museum at Paris a specimen of a Melon, marked in this manner with close series of white spots. The purple colour of some shells is also changed under a similar treatment to dusky red; and it is by this process that the red spots are formed on the polished muscle-shells and uncoated Nutmeg Cowries, which are so abundant in the shops. A very curious effect is produced by ink on some purple shells, which I have seen only in individuals of that colour. On the receipt of the CRACHERODE collection of shells at the British Museum, my uncle, Dr. GRAY, wrote on each of them with a pen and ink the number of the catalogue and the name of the species. In many instances, although the ink has been washed off, the name and number are still distinctly visible, forming an evenly raised letter as broad as the ink line, and slightly interrupted, as if by bubbles, in a few places. This is particularly visible in the specimen of *Solen diphos*, No. 186. in that collection. The effect, however, is not produced in all shells of this colour, nor even in some of the same natural genus which were written upon at the same time; but as I have observed it in a few other purple shells, and as I have not met with it in any of a different colour, I am inclined to think that the nature of the colouring matter may have some share in its production.

3. *The Structure of Shells.*

Shells exhibit, when examined, two very distinct kinds of structure: in the one case the calcareous particles of which they are formed are crystallized, in the other they are granular. These differences in structure correspond with differences in their chemical character, the shells in which the lime is crystallized appearing to contain less animal matter than the others. The primary division of shells according to their structure consequently agrees with the division proposed by Mr. HATCHETT, in his paper on their chemical composition; the porcellaneous shells of that distinguished chemist being crystalline, and the nacreous granular.

Shells of the crystalline structure are themselves of two very distinct kinds; the crystals being rhombic in some, and prismatic in others.

Those of the rhombic crystalline structure exhibit, when broken, three distinct layers of calcareous matter. On examining fragments of most of the spiral univalves, there will be observed on two of the fractured sides of the cubic pieces into which they generally break, flat surfaces on the inner and outer edges, separated from each other by a shelving portion in the centre; and on the two intermediate broken sides shelving external and internal edges, connected by a flat central portion; these differences of surface being produced by the different position of the crystals of the different layers.

Each of the three layers thus rendered obvious is composed of very thin laminæ, placed side by side, as high as the thickness of the plate and perpendicular to its surface. When these laminæ are minutely examined, they will be found marked with obscure oblique lines; in the direction of which they separate, when broken, into long narrow rhombic crystals. The lines of cleavage in the succeeding laminæ are placed in contrary directions, so that when two of these plates united are examined under the microscope, the lines of cleavage appear to cross each other at right angles, whilst those of the alternate laminæ follow the same direction.

The laminæ of the outer and inner plates are always directed from the apex of the cone of which the shell is formed towards its mouth; in the spiral shells they consequently follow the direction of the spire. On the contrary, the laminæ of the plate situated between the other two, form concentric rings round

the cone parallel with its base, and cross at right angles those of the inner and outer layer. This decussation of the laminæ of the plates, and of the crystals of the laminæ themselves, adds considerably to the strength of the shell, and accounts for the great difficulty that is found in breaking many shells of this structure, more especially the Cones and Olives, in which, however, nearly the whole of the strength resides in the outer whorl and in the spire.

A good illustration of this structure may be obtained by examining with a pocket-glass the fractured edge of a Cone, Olive, or other spiral shell, in which the *extremities* of the laminæ of the outer and inner plates, and the *sides* of those of the central layer, or the converse, will be observed, according to the direction of the fracture; the extremities of the laminæ showing the angles of the crystals, while their sides, when closely examined, will often exhibit the crystalline flakes. In order to observe the lines of cleavage, the best mode of proceeding is to bruise part of a shell with a hammer, and to examine the fragments moistened under a microscope, until one is discovered which exhibits two laminæ in conjunction. The plates and their structure are also well seen in the polished surfaces of shells which have been slit or ground down to exhibit the internal structure of their cavity. The relative thickness of the three plates varies in different species; but as far as I have yet examined, the central plate is generally rather the thickest, and the outer one the thinnest. The Italian cameo cutters appear to be aware of this circumstance, and avail themselves of it in cutting the cameos, the ground being always formed of the innermost layer of the three, which is also generally the most transparent.

The layers increase in thickness from their inner to their outer edge, each of them being formed by successive depositions of thin coats of animal and calcareous matter on its inner surface until it acquires the proper thickness for the shell, the outermost edge of which is very thin, and has during the progress of the growth little calcareous matter, but gradually passes into the periostracum.

This *accumulation* of calcareous particles, deposited at various times and nevertheless forming the same crystals, is well illustrated in the prismatic crystalline shells. These are also evidently formed of several layers, which in some instances, as in the *Pinnæ*, are distinctly separate from each other: if, however, the shell be cracked transversely to its layers, the crystals will be found conti-

nued across the line which separates them. An analogous structure exists in some minerals, the Hæmatite for instance, the balls of which appear to be formed of separate concentric coats, but nevertheless when they are broken exhibit the crystals radiating from the centre to the circumference without interruption.

The plates of which the rhombic crystalline shells are formed are deposited in succession, each gradually increasing in thickness as the shell enlarges, and undergoing no variation in this respect after the deposition of the succeeding coat has commenced. That the coats are deposited in regular succession, may be seen by examining the lip of any shell which has been taken whilst the animal was increasing its size. At this period the lip will be found gradually shelving and becoming thinner from the inner to the outer edge, the innermost part being formed of three, the next of two, and the outer and thinnest part, which is always the first formed, of only a single layer. This is best seen by making a section of the lip of a *Strombus* or a *Cone* along one of the spiral grooves, in which, if the polished edges be examined, the layers will be distinctly seen. When the animal is about to make its periodical stoppage of growth, the second, and afterwards the innermost layer is deposited up to the edge of the mouth, which is thus completed.

In the *Olivæ*, *Ancillariæ*, and some *Volutæ*, which have, at all periods of their growth, a polished surface, (now known to be caused by their shell being more or less immersed in the large foot of the animal,) the outer layer, although equally crystalline, is very thin. It is harder and much more compact than the others, and between it and the central layer is deposited an opaque, white, powdery film, which often causes it to break off in splintery flakes, while the rest of the shell separates into fragments, generally more or less cubical, their shape depending, doubtless, on the rectangular disposition of the laminæ of which the plates are formed.

Some Olives, as *Oliwa utriculus*, *O. undatella*, and *O. acuminata*, have an additional band, in structure and hardness resembling the outer coat, forming a belt over the latter, across the front of the whorls; and some *Ancillariæ*, as *Ancillaria marginata*, have also a similar belt placed on the back of the volutions.

When the animals of many of the shells of this structure arrive at their full

size, or when they form the successive mouths of their shells at their periodical stoppages of growth, they deposit a considerable number of layers of shelly matter, either on the lip or on the pillar: these layers are formed of laminæ disposed in the same manner as those of the inner layer of the body of the shell, and, indeed, may be considered as repetitions of this part.

The animals of some genera, as for instance *Cypræa*, *Ovula*, *Erato*, and *Marginella*, deposit, at the same period, on the outside of their shells an additional coat covering the lip and back, which may also be considered as a continuation of the inner layer, since it agrees with this layer in the position of the laminæ: it changes its character, however, on becoming external, being harder, more compact, and often differently coloured. In all these cases the sides of the mantle of the adult animal are expanded into wing-like processes, which are reflected over the shell, and deposit the additional layer. In the *Cyprææ*, *Erato*, and *Ovula*, in which the lobes of the mantle are large and nearly meet, there is left a differently coloured line at the place of their junction, which, on account of the left lobe of the mantle being usually the largest, is generally situated on the right side of the back, and is called the dorsal line: this line is not observed on the *Marginellæ*, the lobes of the mantle being in them less developed, and leaving a broad uncovered space on the back.

It is probable that the polished coat of the *Struthiolaria oblita* is formed in the same manner, but the animal of this shell has not been examined. From the reflected form of the lip, however, in other species of that genus, and from the edges of the mantle in the other genera of the family of *Strombidæ* (to which *Struthiolaria* evidently belongs,) becoming developed when the animal attains its full growth, as is proved by the expansion of the lips of the *Strombi* and the lobed form of those of the *Pteroceræ* and *Rostellariæ*, it is easy to suppose that its lobes may even become completely reflected.

The species of *Cymbium*, when fully grown, or under particular circumstances, are often covered externally with an additional glazed coat, which is apparently deposited by the foot, as the animals of these shells do not appear to be provided with large lobes to their mantle. This coat being deposited over the periostracum, is liable to be broken off.

There is deposited on the sides, and more especially in the posterior part, of the cavities of the upper whorls of many of the spiral univalves, a transparent

calcareous concretion, which lines, and more or less fills up the cavity. This deposit may be observed lining the cavity of the upper whorls of *Mitra episcopalis*, *Triton pileare*, *Cassis glauca*, *Voluta hebræa*, and several other shells. In some, which have an elongated acute spire, as in the various species of *Fasciolaria*, and in the turreted shells, such as the *Terebræ*, *Cerithia* and *Turritellæ*, it entirely fills the cavity of the tips, which, from their small size and original thinness, would otherwise have been liable to be broken. Its deposition is not confined to adult shells, for I have observed it filling the cavity of the upper volutions, and lining the succeeding ones, in a slit specimen of a young *Strombus gigas* in the possession of Mrs. J. P. ATKINS, to whom I take this opportunity of expressing my thanks for her kindness and liberality in allowing me to examine the numerous dissected shells in her collection.

In those Volutes which retain the nucleus (or that form which the shell has when first hatched,) that part, which was originally very thin and brittle, is speedily filled up with the deposit in question. In fact, all shells whose spires are exposed, and, being thin in their young state, would be liable to be broken off by the action of the sea, have that part strengthened by the internal deposition of calcareous matter.

The distinction between these and the decollated shells, such as *Bulimus decollatus*, *Cerithium decollatum*, &c., is, that in the latter, the animal, instead of lining the upper whorls with an internal coat, suddenly withdraws its body from them and forms behind its extremity a concave septum; and the vital communication between the body and the apex of the shell being thus cut off, the latter part decays, in the manner of a dead shell, and falls off in particles*.

The greatest development of the deposit mentioned above is to be observed in the genus *Magilus*, in which the young shell is very thin, shaped like a *Purpura* and of a crystalline texture; but when the animal has attained its full size, and has formed for itself a lodgement in a coral, the greater part of the cavity of its shell is filled with a glassy substance, leaving only a small conical space for the reception of its body: layer after layer of this substance are then deposited in rapid succession, in order to keep the body of the animal on a

* M. DE BLAINVILLE refers the decollation of the spire to the inner surface of the cavity of the shell becoming filled with a very brittle glassy deposit.

level with the top of the growing coral in which it is buried, until its shell is almost lost in the quantity of glassy matter subsequently formed.

The shells of the prismatic crystalline structure exhibit, when broken, a quantity of short fibres perpendicular to the surface: when examined, these are found to be mostly hexagonal prisms, with a few smaller polyhedral prisms interposed. This structure, which has been repeatedly described, is to be observed in the tube of the large *Teredo* from Sumatra, in the vitreous deposit of *Magilus*, and in many bivalves, especially those which belong to the families of *Mytilidæ* and *Aviculidæ*, as the *Pinnæ*, Mother-of-pearl shells, &c.; and it may likewise often be seen in fossil shells, such as the *Inoceramus*, fragments of which, exhibiting this structure, are frequently found imbedded in flints.

On the other hand, shells of the concretionary structure exhibit, when broken, a nearly uniform texture: they separate, when heated, into numerous thicker or thinner laminæ; and when digested in weak muriatic acid, the lime is dissolved, leaving a great number of thin plates of animal matter, which retain the original shape of the shell. In general, the plates of which these shells are composed are very thin, and closely applied to each other, forming by their union a hard and compact texture.

The pearly or iridescent lustre appears to be confined to shells of this texture, in which it is very general; a circumstance which induces me to believe that this lustre depends in a great measure on the thinness and number of the laminæ of which the shell is formed*.

This variety of structure is found to constitute the whole shell of the *Anomice* and *Placunæ*; and to form the inner coat of those shells which have pearly insides, as the *Turbines*, *Haliotides*, *Uniones*, &c., as well as the laminar portion of the *Pinnæ* and Mother-of-pearl shells.

When such shells disintegrate, they separate into very numerous thin lamellar scales of a pearly grey colour and silvery lustre. The Chinese are aware of this circumstance, and use the particles of the disintegrated *Placunæ* as silver in their water-colour drawings. I have myself used some of this silvery powder, brought to England by Mr. REEVES, for the same purpose, in colouring the figures of fish, with good effect: it is not quite so brilliant as the

* The iridescence of the *Turbinella prismatica* and of *Bulinus cactivorius* appears to depend upon the texture of the periostracum.

powdered leaf metal, but it has the advantage of not changing colour by exposure.

In some shells of this structure the layers are thicker, and the animal matter is deposited in larger quantities, giving the shell a foliaceous appearance. In these the calcareous particles are large, opaque, white, and earthy, like chalk. This is well exhibited in the common Oyster; and is also found, not so distinctly developed, in the *Pectines*, and on the outer surface of those shells which are internally pearly, such as the *Haliotides*, *Turbines*, &c. The animal matter between the laminæ is sometimes very unequally deposited: it is found forming large brown spots in the pearly coat of many of the *Haliotides*, especially in the *Haliotis Midæ*, and *H. splendens*, in which these spots produce beautiful variations in the colouring and pearlyness of the shell.

In many of the fresh-water bivalves there is deposited between the layers of the shell a lamina of animal matter, similar to the periostracum. In the genera *Etheria* and *Mulleria*, such a coat is deposited between nearly all the layers, giving them a very peculiar olive-green colour, and having minute dots on its surface. The shells in question appear to be extremely liable to be eroded by the water, and these successive depositions of animal matter enable them to offer a new layer of periostracum to protect each succeeding plate, as the one above it gives way to the destructive influence of the medium in which they reside. A similar deposit of animal matter is also often found forming green stains in the pearly inner coat of the various species of *Uniones*, and it sometimes protects from the action of the water the inner part of the umbones of shells which have been eroded. In the upper valve of *Ostrea cornucopiæ*, I have observed the thick inner layer to be rather prismatic, and the outer part of the laminæ to be separated by layers of periostracum.

In some shells of this kind, there are left between the plates larger or smaller spaces, which are generally found filled with water. These spaces are sometimes met with in the common Oyster, and they occur not unfrequently in a large *Spondylus*, which is known to the dealers, on this account, by the name of the *Water Spondylus*. In the latter shell it is not unusual to find these cavities, which are sometimes of a large size, in both the valves, recurring one on the top of another, and giving the valve, when cut through, the appearance of a chambered shell; but having no siphon passing from one septum to the other. There

can be little doubt that these laminæ, the concave plates at the end of turreted shells, and the septa of the regularly chambered shells, are all deposited in the same manner, the body representing the model on which they are formed. But it is not so easy to understand why such cavities should be left in these shells, especially in the upper valves, as it is to account for the existence of the analogous structure in turreted and chambered shells, the flat form of their valves enabling the animals of the former, as we might suppose, to extend the diameter of the existing cavity, when larger space was required for their accommodation, without constructing one altogether new. In the *Etheriæ*, cavities in the form of small vesicles, or very thin bladders, are also left between the plates. The cavities in the *Ostreæ*, *Spondyli* and *Etheriæ* are, I have reason to believe, filled with water when the animals are alive; and this also appears to be the case, from Mr. GEORGE BENNETT'S account, with the chambers of the *Nautilus*; but the water soon evaporates through the pores of the shell, if kept in a dry place. I have never observed this peculiarity except in these bivalve shells which are immediately attached by their outer surface to other bodies.

Many shells are composed entirely either of the rhombic crystalline or of the concretionary structure; but I know only of a single instance (and that occurs in the tube of a shell,) in which the whole mass affects the prismatic crystalline structure. In all other shells of this latter texture, the inner and front part, which is occupied by the body of the animal, is always covered with a coat of the laminar concretionary texture.

4. *On the Power possessed by Mollusca of dissolving Shells, Rocks, &c.*

It has been generally believed, and indeed sometimes most positively asserted, that Molluscos animals do not possess the power of reabsorbing the matter of their shells when once deposited. The following observations, I think, will distinctly prove that this theory is quite unsupported by fact.

If a Cone, an Olive, or any shell whose last whorl almost completely envelopes and protects the rest, and whose cavity is much compressed, allowing only a small space for the convolutions of the body of the animal, be slit down, either from the apex to the front of the axis, or across the body volution, at a little distance before the suture, it will be observed that all the septa between the different whorls are extremely thin and transparent; and when these septa

are minutely examined, they will be found to consist of only a single one of the three plates of which all such shells are originally composed, which plate will be seen to agree in structure with the inner one of the three. On tracing these septa to the outer whorl, it will be observed that every part of them, during the various stages of growth of the shell, has been once a part of the outer whorl; and since we know from experience that the outer whorls of the young Olive and young Cone are as thick in proportion to their size as those of the adult, there is little reason to doubt that each of these septa was originally formed of three plates, in the same manner as the other parts of the shell. That this was actually the case, and that the part remaining is the continuation of the inner plate, the other two plates having been removed by absorption, may be proved by the fact that the other two layers of the same volutions are distinctly visible on the exposed part of the spire, and on the front part near the pillar, while they are deficient only on the thin part of the septa; and if the outer half of the penultimate whorl, or rather the half-whorl just within the mouth, be examined, the two outer layers will be found to be there only in part absorbed, leaving a shelving edge directed towards the cavity of the shell*.

A still stronger instance of the absorption of the septum may be observed in the shells formed by some of those Mollusca whose respiration is effected by means of lungs, as, for instance, the *Auriculidæ*. In the young shells of this family the septa which separate the whorls are incomplete, and twine nearly parallel to each other. As the shells increase in size, the later formed septa become much more oblique and broader, and at length completely separate the cavities of the whorls. When, however, the animals of many of the species, especially those of the *Melampi*, approach maturity, the whole of the septa, except the outer half of the penultimate volution, are absorbed, leaving a simple cavity in the upper part of the shell. On further examining the remains of the septum, it will be found that the absorption has taken place on the outer

* It is probable that some Bernard Crabs have also the faculty of dissolving shell, for it is not unusual to find the long fusiform shells, (such as *Fusus*, *Fasciolaria* and *Turbinella*,) which are inhabited by these animals, with the inner lip and great part of the pillar on the inside of the mouth destroyed, so as to render the aperture much larger than usual. I have never seen this erosion except in dead shells which had been inhabited by Hermit Crabs; but it does not occur in all that are so tenanted, for I have also observed these animals occupying the shells of *Fusi*, &c. in which the lip was in its usual state.

side, as is proved by the surface shelving down to form an acute edge on its inner side.

A similar absorption may be observed in the inner whorls of the *Harpa articulata*; but it is in this case confined to the central part of the septa, and all the coats are partially dissolved, so as to leave a slit between the cavities of the different whorls. An absorption of the upper septum also takes place in some of the *Neritimæ*, as the *Neritina fluviatilis*; and it was on a character derived from this circumstance that DE MONTFORT established the latter shell as a genus under the name of *Theodoxus*.

These facts distinctly show, that as the animal enlarges the mouth of its shell, it absorbs in a greater or less degree the substance of the inner whorls. This process of absorption, besides furnishing the animal with calcareous matter towards the enlargement of its shell, gives more space for the lodgement of the body, and renders the shell far lighter to carry; and these advantages are gained without in the slightest degree detracting from its strength, as the outer whorl and spire, which are alone exposed in shells of this form, remain at least as thick as in most other shells.

In many other univalves, the animal, before depositing the laminæ which form the inner part of the mouth, absorbs the outer layer of the penultimate whorl, as is evidenced by the ridge with which that part is often surrounded. This is particularly the case in the various species of *Turbines*, as in *Turbo coronatus*, *T. smaragdus*, *T. sarmaticus*, and in some *Fusi*, as *Fusus despectus*. But it is most distinct in the *Purpuræ*, where the Lamarckian character of the genus depends upon this absorption, which causes the concave flatness of the inner lip. In the *Murices*, and other shells which have spines or branching appendages on the front of the whorls, the site of which appendages the succeeding whorls must overlap, these processes are generally absorbed by the animal before it produces the inner lip over their base, as their length would otherwise offer an obstacle to the regular progress of the shell. This absorption of the outer part of the last whorl but one, and of the spines, is evidently effected by the edge of the mantle. In specimens taken while the process is going on, there may be observed a notch, formed by this means, in the base of the spines or processes, the completion of which causes them eventually to separate from the shell. A similar effect is produced on a new species of Sun Trochus, *Imperator*

Guilfordia, where the keels of the whorls are furnished with a central series of spines, which are removed before the mouth of the shell is continued.

In some shells, however, which have only short processes, as in the variety of the *Pyrula bucephala* with two rows of spines, the front rows are not absorbed, the inner lip being deposited of such a thickness as to cover them. A similar circumstance may be observed in a monstrous variety of *Strombus pugilis*, with two rows of spines, of which there is a specimen in the British Museum.

In the young state of the *Fissurellæ*, the hole by which the fæces pass out of the shell is placed a little in front of its recurved and spiral apex: in this state it has been formed into a genus under the names of *Rimula* and *Puncturella*. But as the animal grows, the hole enlarges in size backwards, and the true apex being absorbed, the hole appears in the adult shell to be placed on the tip, and in some species even to extend behind it.

The animals of many species absorb parts of their shell at regular periods: thus the Tritons, which at each of the periodical interruptions of their growth form a thickened edge to their lips, when they again commence enlarging their shells, generally absorb this thickening both as regards that part which had been deposited on the pillar and that which formed the ribs and teeth of the outer lip; for on examining the cavity of any of these shells, it will be found quite smooth and free from interruption. Such an absorption does not, however, take place in some of the larger *Cassides*, and in the genus *Persona*, in which the thickening of the former lips remains after the shell has enlarged in size, and forms prominent bands on the parietes of its cavity. But a similar periodical deposition and absorption of the thickening of the outer lip takes place in many of the land shells, as the *Helices* and *Bulimi*; in most of which there is formed, at every interruption of their growth, an internal rib, just within the edge of the mouth, which is removed when the animal again begins to increase its shell. This is particularly visible in the genus *Scarabus*, where the interruptions are regularly periodical, each period of growth occupying half a whorl, as in the *Ranellæ*.

Mollusca not only have the power of absorbing their own shells, but they also possess the faculty of forming cavities in those of other animals. When a specimen of *Pileopsis* attaches itself to the surface of a shell, it generally leaves

in the place of its attachment a depression of its own size, and furnished with a horse-shoe-shaped ridge: such cavities are sometimes formed even in other specimens of the same species. It appears moreover to be of little importance how great may be the hardness, or what may be the structure, of the shell on which they fix; all yielding with equal readiness to their absorbing powers. It is not unusual to find holes thus produced nearly a quarter of an inch in depth in the very hard external coat of the larger *Turbines*; and similar depressions are found in *Purpuræ*, *Strombi*, *Fissurellæ*, *Chitones*, *Patellæ*, &c.

The animals of *Siphonaria*, *Patella*, and an allied genus* (*Lottia*), which appears to be peculiar to the coast of South America, have the same faculty, but in a less degree, and the cavities formed by them are destitute of the horse-shoe-shaped ridge. The depressions produced by the *Siphonaria* and the *Chitones* have, however, an unequal groove round their margin, which is largest and deepest on one side, occasioned probably by the shell being generally raised on the opposite side to admit of the access of air to the branchiæ. The *Patella cochlea* is often found at the Cape of Good Hope, where it lives almost exclusively, attached to a large species of the same genus, on the surface of which it forms a flat disk, exactly the size of its mouth. To form these flat disks, (of which there are so generally two, one on each side of the apex of the larger *Patella*, as almost to form a character of the species,) and to assist in the increase of its size, the animal appears also to absorb the coralline or other similar substances with which the larger shells are abundantly covered. The common *Patella* of our own coast, when long adherent to another shell of its own species, to chalk, or to old red sandstone or limestone, also forms for itself a deep cavity of the same form as its shell, and evidently produced by the dissolution of the surface to which it is affixed.

The animals of the several species of *Vermetus*, especially of that called by DAUDIN *Spiroglyphus*, have the faculty of producing by absorption a groove in the surface of many very hard shells, such as the *Trochi*, *Haliotides*, and *Fissu-*

* This genus must be extremely perplexing to those systematists who attend only to the form of the shell without paying any regard to its animal inhabitant. The shells of *Patella* and *Lottia* do not in the least differ in external form, and yet their animals belong to very different orders, the one having the branchiæ placed round the foot, as in the Chitons, and the other having them placed on the side of the neck, like the *Fissurella*, from which indeed it chiefly differs in having only one branchia.

rellæ; which groove they cover with a calcareous deposit, and thus form it into a tube. The history of *Spiroglyphus* is altogether peculiar: the young animal, when first hatched, is covered with an ovate regular spiral shell, consisting of a whorl and a half, and in appearance very like the young shell of *Magilus*, with which, indeed, its affinity is very striking; it soon attaches itself to the surface of a shell, in which it commences the formation of a canal, narrow and shallow in the first instance, but becoming deeper and wider as the animal increases in size. Both the canal and its shelly covering retain for some time the regular discoidal spiral form, and the whorls are sometimes so closely impressed on each other, that the animal actually absorbs part of the tube which it had previously deposited, in order to make room for its new whorl. In one instance which has fallen under my observation, it had left only a very thin transparent plate between itself and the cavity of the tube. When, however, the animal has nearly attained its full size, the shell assumes an irregular form, and is sometimes extended into a straight line, and at others closely twisted over its former shell, which, under such circumstances, it often absorbs. It is not uncommon to find several young animals of this genus burying themselves in the tube of an adult shell.

These unequivocal instances of the power of the Mollusca to dissolve their own shells, and to make holes in the shells of other animals without the exertion of any mechanical force, but by simply applying their foot to the part to be dissolved, afford strong grounds for believing that the holes formed by the regular boring Mollusca, such as the *Pholades*, *Petricolæ*, *Venerupes*, and *Lithodomi*, in shells and calcareous rock, are produced in a similar manner; and this belief is strengthened by the following considerations:

1st. That the animals of most of the boring shells are furnished, like those of which I have just been speaking, with a large foot, more or less expanded at the end.

2ndly. That the holes bored by some of the *Petricolæ* and *Gastrochaenæ* are compressed, and so exactly fit the shell, that it would be impossible for the latter to rotate on its axis in such a manner as to use the asperities of its surface for the purpose of rasping, as some conchologists have supposed. I have also seen specimens of *Pholas pusillus*, the back valves of which were so much distorted, as to demonstrate the impracticability of such a process, a

projecting part of the back having evidently been fitted into a cavity on one side of their cell; yet these *Pholades* appeared to have enlarged subsequently to the distortion having taken place. Those of the Barnacles which bore, such as the genera *Conchotrya* and *Brismeus* (and probably *Lithotrya*), form an oblong compressed hole, of the exact size of their shells. Specimens of *Brismeus*, in my collection, are attached to the side of an oyster-shell, in which they have destroyed part of two or three plates to form such a cavity; but although the shells of these boring Cirrhipedes are furnished with raised lamellæ, the projections are placed across the valves in such a manner that no motion that could be given to them would enable them to rasp a hole.

3rdly. That all the boring shells are covered with a periostracum, which is thin in the *Teredines*, *Pholades*, *Laseæ*, &c., and thick in the *Lithodomi*, and which, if the animals used the outer surface of the shell as a means of boring, must be very speedily rubbed off. Such a fact would be readily observed, as this part is never renewed after having been once destroyed; which is easily understood when we consider, that it can only be formed on the edge of the shell before the deposition of the shelly matter has advanced beyond it.

4thly. That although the shells of *Teredines*, *Pholades*, some *Petricolæ*, &c., are covered with short spines and striæ by means of which they might be supposed capable of rasping stones, other boring shells, such as the *Laseæ* and *Lithophagi*, are smooth.

5thly. That I have not observed shells of this kind to bore into any other substances (wood excepted,) than shells, calcareous rocks, clay, marl, chalk, limestone, and sandstone united by a calcareous cement; nor do such shells, as far I have seen on the coast of Devon, attack the latter rock, except when it has lain a long time under the sea, and become as soft as clay. Colonel MONTAGU states that he has seen specimens of *Gastrochaena* which had bored into fluorspar and granite; but an examination of his specimens in the British Museum proves that what he regarded as fluorspar are merely crystals of carbonate of lime; and although the shell is not uncommon on the coast of Cornwall and Guernsey, I have never seen it produce the slightest impression on the granite rock, even in its disintegrated state. Instead of attempting this, the animal changes its habits, and generally chooses a slight crack in the granite rock, in which it forms for itself, like some of the fossil species of the genus called

Fistulana by LAMARCK, a calcareous case, partly constructed of such fragments of shells or stones as may be thrown within its reach. The granite, indeed, appears completely to resist all the dissolving powers of the Mollusca. Thus in some structures, as the Plymouth Breakwater, for instance, in which limestone and granite are employed together, and placed side by side, the *Patellæ* form their rounded holes in the former; while they do not in the slightest degree alter the surface of the latter, except in general by clearing from off it any calcareous substance which may have previously grown upon it. I have one specimen beautifully illustrating this latter fact, a young *Patella* having affixed itself to the shelly base remaining from a Barnacle, in which it has dissolved only the part beneath its foot, leaving the rest forming a ring around its shell.

Many of the boring Mollusca, especially the *Lithodomi* and *Petricolæ*, cover the hinder part of their shells with a calcareous coat, which is often of a spongy texture, and differs from the shell in internal structure. This is probably the dissolved part of the rock again deposited. Many also of these animals, as the *Gastrochænæ*, *Clavagellæ*, and *Teredines*, secrete constantly, and others, as the *Lithodomi*, under particular circumstances, a calcareous deposition, with which they line the inner surface of their holes.

The determination of the existence of this power of dissolving shell and calcareous matter does not, however, remove the difficulty with regard to those shells which bore into wood; although it is not impossible that this substance may also be dissolved by the same means. And this appears to me the more probable, as, although there are some species of *Pholades*, such as *Pholas pusillus* and *P. rudis*, which I have never seen in any other substance, I have found others, such as *P. dactylus* and *P. candida*, indiscriminately in chalk, marl, limestone, red sandstone, and wood; and it is difficult to suppose that these species adopt different means of boring when employed in penetrating the latter substance.

Possessing this power of absorbing their own shells, the shells of other Mollusca, and calcareous rocks, it is remarkable that these animals do not exert it for the purpose of removing extraneous obstacles which may oppose their progress in the formation of their shells. In the collection of the British Museum is a specimen of *Pyrula bezoar* that appears to have grown with perfect regu-

larity until the formation of its last half-whorl, which is thrown considerably more than half an inch out of its proper position by a group of Barnacles. These shells had probably attached themselves to the back of the *Pyrula* at an earlier stage, and, as the latter increased in size, at length filled the place that should have been occupied by the inner lip, which, on meeting with this interruption, diverged from its course, and was thrown over the Barnacles. Had the shell not been taken until a later period, there can be little doubt that the animal would have at length destroyed the Barnacles, and completely hidden them from view, by continuing the whorl entirely over them; although it would appear that it had not the power to remove them by absorption while they retained their vitality. In the same collection there is also a specimen of *Strombus luhuanus* the spire of which has been much distorted in consequence of the temporary attachment of some parasitic shell, which subsequently became loose and has been detached.

In the collection of my friend Mrs. MAUGER is a specimen of *Helix aspersa*, showing a similar deformity arising from the same cause; but in this case the obstruction has been produced by a young shell of the same species. The young specimen is attached to the spire, to which it had doubtless fixed itself during the dry season; and not awaking from its torpor so early as its older companion, the latter, when it commenced increasing the size of its shell, threw its new whorl partly over the smaller individual, which was thus inclosed in a prison formed by its own shell. In this instance, the form of the larger specimen is not much altered; but about one half of the young shell projects above the spire.

In like manner, the Cowries, and other shells which have an additional coat deposited on their back by the enlarged lobes of the mantle, on arriving at the adult age, cover in with this coat any body which may be accidentally attached to their surface. There are two specimens of *Cypræa rattus* in the collection of Mr. GASKOIN, on one of which a *Crepidula*, and on the other a Barnacle, is evidently so inclosed; and HUMPHREYS, in the PORTLAND Catalogue, described two specimens of the same shell in which he had observed a similar occurrence. Such accidents appear, however, to be rare, the extension of the mantle having in itself a strong tendency to prevent other animals from adhering to the surface of these shells.

A similar occurrence may frequently be observed in the shells of the genus

Cymbium, the glazed coat of which often includes *Balani* and particles of sand. The presence of such bodies under the glazed coat in these shells is so constant, that I am inclined to believe that the animal deposits this coat with the view of ridding itself of the irritation caused by the adherent sand and Barnacles rubbing against its foot, as the animal of the Chinese Pond Muscle (*Dipsas plicata*) deposits its pearls over buttons or spines which are artificially introduced into its shell.

5. *On the Deposition of Shelly Matter by the Foot.*

It has been very generally supposed, that the calcareous matter of which shells are formed is secreted only by the mantle of the animal; and it has consequently been taken for granted, that the expanded base of the *Cassides* and *Personæ*, the broad inner lip and the closed back of the *Cymbia*, and the polished coat on the outer surface of an *Oliva* or an *Ancillaria*, were each and all deposited by some expansion of the mantle.

I have lately, however, had an opportunity of observing the animals of all these, and of many other genera, in the Museum of the Jardin du Roi at Paris, where my excellent friend Professor DE BLAINVILLE, who was at that time keeper of this part of the collection, kindly allowed me to examine at my leisure all the stores of Mollusca collected together for a long series of years by the late Baron CUVIER, as well as those brought home by MM. QUOY, GAIMARD, and LESSON, from the recent voyages of discovery in which those naturalists took part. At the same time I was allowed, by the kindness of M. QUOY, to consult and copy the numerous drawings made by him, during his voyage, from the animals whilst alive and walking about. From this examination I am enabled to state, that in all the shells just named the shelly matter in question is deposited, and most probably secreted, by the upper surface of the foot, which is very large, and not by the mantle, which, on the contrary, is small, and not expanded beyond the edge of the mouth. This is most obviously the case in the *Cymbia*, *Olivæ* and *Ancillariæ*, which have so large a foot that the shell appears to be actually immersed in it. Animals of these genera, drawn from life, are figured by ADANSON in his Voyage to Senegal, and by FORSKAHL in his Fauna Arabica. The *Murex anus* of LINNÆUS, which has been referred by LAMARCK to his genus *Triton*, differs in this particular from

all the other animals placed by him in that group, and agrees with the genus *Cassis*, the expanded base round the mouth being produced by the very widely expanded foot : it forms the genus *Persona* of DE MONTFORT.

It is remarkable that this fact should not have been before observed, more especially as the operculum of all molluscos animals which are furnished with such a protection is secreted by the back of the hinder part of the foot, where there is no extension of the mantle.

6. On the Operculum.

The part usually called Operculum is a horny or shelly plate, adherent to the back of the hinder part of the foot of many Gasteropodous Mollusca. It is always (except perhaps in *Navicella*,) attached to the free end of the large muscle by which the animal is affixed to its shell ; by the contraction of which the operculum is brought into such a situation as more or less completely to close the mouth of the shell when the animal is drawn into its cavity. It has hitherto been observed only in those Mollusca which have pectinate branchiæ, and in two genera (*Cyclostoma* and *Helicina*) amongst the pneumonobranchous land shells.

The muscle by which the animal is attached to its shell is generally affixed to the hinder part of the cavity, a little within the mouth : in the long spiral shells, which have a small or moderately sized mouth, it is simple, and forms a single scar on the pillar ; but in those which have a large mouth and a slightly developed spire, as *Neritina* and *Nerita*, it is divided into two portions, one attached at each end of the pillar lip ; and in those which have the mouth almost as large as the cavity of the shell, such as *Capulus*, it is divided into two nearly equal parts, which extend along each side of the cavity, and form what is generally called a horse-shoe-shaped muscular scar. The insertion of the muscle forms similar scars on the inner side of the operculum. Thus in most opercula there is only a single scar : in those of *Nerita* and *Neritina* there are two scars, one at each end ; and in *Capulus* the operculum has a horse-shoe-shaped impression. The only exception, as far as I am aware, to this rule, is in the genus *Concholepas*, where the muscle forms a continuous band nearly round the cavity of the shell, while the operculum, which is very small, is marked only with a single subcentral ovate scar.

By far the greater number of these bodies are formed of a more or less condensed cartilaginous matter, similar to the periostracum; and they are often strengthened by a deposit of calcareous shelly matter on their outer side, or more rarely by a similar deposit of greater or less thickness on their inner surface, in some few instances extending to both. The deposit on the inside may be compared to the glassy enamelled coat which is found in the cavities of certain shells, and that on the outer surface may be considered analogous to the hard enamelled coat covering the backs of the Cowries. A few opercula, such as those of the genus *Neritina*, appear to be truly shelly.

The opercula agree with the valves of shells in being developed on the embryo while included in the egg, and in increasing in size by the addition of new matter round the circumference of the base of the cone of which they are formed: they also agree in the cone being sometimes simple and straight, and sometimes curved into a spiral form. That ADANSON regarded them as analogous to the valves is evident from his calling the shells which are provided with these lids on their mouths *Sub-Bivalves*. The principal difference, indeed, between the operculum and the valve of a shell consists in the former having no cavity, the cone of which it is formed being either very much depressed, so as to become nearly flat, or even concave, as in the annular or some subannular opercula, or very much compressed, forming only a spiral ribband, as in the spiral ones. Opercula are never attached to their shells by ligaments or by any other means than that of the adductor muscle; and they are always free, except in the genus *Capulus*, which offers a remarkable anomaly in this part being immediately attached by its outer surface to other marine bodies.

It is proper to observe, that in describing the operculum I have called that the anterior margin, which is nearest to the pillar of the shell, as when the animal is walking this part is directed towards its head; and the right and left extremity are the parts corresponding with the right and left sides of the body. When the operculum is placed in this position, the left end is that which fits into the front, and the right that which corresponds to the hinder part, of the mouth. This distinction of parts may, at first sight, be thought trifling; but to the practical zoologist its importance is very great. The position of the nucleus of the operculum is, for example, almost the only conchological character by which four distinct genera of shells can be divided into groups, although their

animals differ both in external form and in internal anatomy. In the genera *Bithynia* and *Paludina*, which have the nucleus of the operculum nearly central, the animal has short tentacles and no air bag; whilst in *Ampullaria* and *Ceratodes*, which have the nucleus of the operculum on its anterior side, the animals have very long tentacles, and a large air pouch by the side of the branchiæ.

Opercula may be divided into three very distinct kinds, according to their form and manner of growth, and these may be again subdivided according to the mode in which they are covered with various deposits.

The annular operculum may be considered the most simple, the very depressed cone of which it is formed being nearly regular, with the apex more or less central, and the coat of new matter, by which it is increased in size, forming complete rings round its circumference; in which particulars it may be compared to the simple conical shells of the genera *Patella*, *Fissurella*, &c. This kind of operculum does not alter its place in the mouth, and the muscle of attachment only moves nearer towards its anterior edge as the addition of new matter on that side renders such a displacement necessary in order to keep the muscle in its proper situation with regard to the pillar of the shell.

The subannular opercula may be regarded as intermediate between the annular and spiral forms, partially combining the characters of each; but I think it better to consider them apart from the others, inasmuch as they are peculiar to those animals of the Ctenobranchous Mollusca, which are provided with a siphon in front of the mantle for conducting the water to their branchiæ, such as the *Murices*, *Buccina*, *Strombi*, *Melaniæ*, *Melanopsides*, *Aulodi*, and the anomalous genus *Phorus*. They are all of a horny texture, and are characterized by their very depressed cone being somewhat oblique, with its nucleus placed at or near the left end, and the lines of growth forming more or less complete rings around it, but always becoming wider apart from each other as they approach the right side. The left end, towards which the nucleus is placed, is generally acute, and the opposite extremity rounded, which is just the reverse of what takes place in the annular opercula, where the right end is acute and furnished with a fold proceeding from the nucleus, and the left side is rounded and broad. In most of the opercula of this division the muscular scar occupies the greater part of the internal surface; is marked with more or less regular

concentric rings ; and is surrounded by a thickened callous deposit, which is broadest on the outer side. This scar appears gradually to approximate towards the right side of the operculum, the part left free, as the scar advances, becoming covered by the callous deposit. The lines on the scar appear to be very constant in the various species, but they are sometimes distorted, and form several centres instead of one. They have no relation to the rings of growth on the outer surface, but have generally a centre of their own placed at some distance from the left end of the operculum ; and they appear to be formed by the successive additions made to the edge of the adductor muscle, which is marked with lines resembling those on the scar. The greater number of these opercula do not alter their relative position in the mouth of the shell ; but a few, like those of *Fusus fornicatus*, in which the end of the cone is slightly curved, move during their lives perhaps to the extent of a quarter or half a turn on the end of the muscle. In some instances, as in the operculum of *Strombus*, where the foot of the animal is very small, the apex or left extremity is obliquely elevated and free : as the rings of growth are added, this extremity elongates, and acquires such a resemblance in form to the claw of an animal, as to have induced the ancients to call such opercula *Elks' hoofs*. The scar of attachment is small in comparison with the size of the operculum, and is situated on its right side : it is cordate and marked with oblique rugose grooves, and with a strong central ridge, which is continued in the form of a rib down the middle of the under side of the free part of the operculum. In some species the posterior edge of the operculum is serrated. In both the annular and subannular divisions, the disk to which the operculum adheres is formed entirely of the muscle of attachment, and of a membranaceous fringe by which its edge is surrounded. This fringe is free from the back of the foot and is widest posteriorly : it doubtless secretes the coat of the layer of growth, and the deposit which borders the edge of the scar, whilst the muscle itself is provided with the means of secreting the proper coat of the scar.

The spiral opercula are so called because the elongated, cartilaginous or shelly, compressed, ribband-shaped cone of which they are formed is twisted into a spire of few or many whorls. In these, the new matter by which they increase in size is deposited only on the extremity of the last whorl, which in spiral opercula may be regarded as analogous to the mouth of spiral shells, as

the entire circumference of the annular opercula, with their subcentral apex, is analogous to the edge of the base of a *Patella*. The lines of growth are marked by curved concentric lines extending transversely across the whorls. Opercula of this character vary much in the number of their whorls: when the whorls are few in number, the cone increases rapidly in size, and the operculum is of an ovate shape, with the nucleus approximated to the left extremity; when the whorls are more numerous, the cone increases in size more gradually, the nucleus is central, and the operculum is more orbicular. In all these cases the edge of the extremity of the last whorl is constantly anterior, that is to say, when the operculum is in the mouth of the shell, this part of it is directed towards the inner lip: when the operculum is ovate and of few whorls, it generally occupies the whole length of that lip; but in the orbicular and many-whorled opercula, it is directed towards the hinder part of the inner lip, near the angle formed by its junction with the outer. Now every time that the animal adds a new layer on the end of the last whorl, the operculum, to allow of this part continuing to occupy the same position, must make a slight turn backwards on its centre, which is the nucleus of the spire, whether the spire be placed towards one end or in the centre of the operculum. This rotation on the adductor muscle, although it may at first sight appear improbable, bears a striking analogy to several other phenomena of the same kind which are continually taking place in the animal economy: I need only instance two well known and apposite examples;—1stly, the gradual change of situation of the adductor muscle as it passes down the pillar of spiral shells, which in some of the long turreted species, such as *Turritella Archimedes*, where there are as many as thirty whorls, must have been carried to the extent of thirty complete revolutions on this part;—and 2ndly, the change of place of the adductor muscle in bivalve shells. In the opercula of the *Littorinæ* and *Naticæ*, which consist of a few very rapidly enlarging whorls, the motion and consequent alteration of position of the place of attachment is very gradual and slow; but in those orbicular opercula which are composed of many gradually enlarging whorls, as in the *Trochi* and *Monodontæ*, the place of attachment must be continually changing, as many complete revolutions being made as there are whorls in the operculum. These are sometimes extremely numerous: in a small specimen of *Turbo pica* now before me, there are seventeen or eighteen, and in some *Trochi*

I have counted still more. In the spiral opercula, which thus rotate on their axis, the nucleus, which is the centre of motion, is always included in the scar, and adherent to the muscle of attachment: it is often furnished internally with a small spiral process, buried in the muscle and resembling the end of a screw. On the contrary, in the annular and subannular opercula, which have no rotatory motion, the nucleus is often removed from the point of attachment, as is well illustrated in those of the *Strombi*.

In many of these ovate or suborbicular spiral opercula which are formed of a few rapidly enlarging whorls, as, for example, those of the genus *Littorina*, the inner surface exhibits the lines of growth as well as the outer, there being in these cases no internal deposit. In these opercula, the adductor muscle is anterior, and occupies more than half the disk to which they are attached, the remainder being formed by a membranaceous flap attached to the hinder edge of the muscle. Along the whole anterior edge of the muscle is a ridge, separated from it by a deep groove, which evidently secretes the additions to the operculum: in one specimen I thought that I could observe the edge of this part attached to the ridge, in like manner as the edge of the periostracum is adherent to the mantle of many bivalve shells.

The operculum of the *Naticæ* is formed on the plan just described; but its inner surface is covered in addition with a smooth pellucid coat, resembling the inner coat of the subannular opercula, and forming a curved tubercle over the nucleus. This coat is marked with two muscular scars, the one lanceolate and central, and the other anterior, linear, and only separated from the first by a narrow polished band; the latter is extended to the back of the tubercle, where it forms a deep oval impression. The adductor muscle occupies the anterior half of the disk, its middle part, which produces the central scar, being of a dark colour, while its front edge, giving rise to the anterior, is white: it is furnished with a thin membranaceous band posteriorly, which is broadest on the right side; and the remainder of the disk is formed of a thick semioval elevated fleshy flap, quite distinct from the back of the foot.

The opercula of some shells which have plaits on their pillar, are very thin, and are furnished with a moveable flap on the left side of their anterior margin, which passes over the plaits. I first observed this in the common *Tornatella*, and afterwards in *Turbo pallidus* of MONTAGU, (the genus *Odostomia* of Dr. FLE-

MING,) and have since verified it in *Pyramidella*. The subannular operculum of *Turbinella cornigera* has a notch on the middle of its anterior margin, and a plait running from the nucleus; but in this case the flap is not moveable.

The opercula of the genus *Neritina* agree with those just described, in their ovate form, and in being composed of few and rapidly enlarging whorls; but they appear to be entirely formed of shelly matter, and are marked both externally and internally with very minute concentric lines of growth. Like the operculum of *Littorina*, they are not covered with any internal or external deposit; but they have several peculiarities. The outer edge of their whorls is furnished with a broad flexible margin; and on the inner side, below the spire, are two diverging processes, the longer of which is curved and forms a tooth, placed near the left end of the anterior edge, which some have supposed to act as a kind of hinge on the sharp inner lip of the shell. The adductor muscle of this genus is divided into two portions, one placed at each end of the pillar: of these the hinder is the largest, and forms a submarginal scar along the end of the last whorl of the operculum, while the anterior is smaller, and forms an ovate scar behind the two processes. The disk to which these opercula are fixed is like that of *Littorina*, and there is a slight ridge extending the whole length of the front edge of the muscle, a little anterior to it, which probably secretes the shelly matter of the operculum: in this office it may perhaps be assisted by the edge of the hinder part of the mantle, situated just before it.

I might have been inclined to regard the operculum of *Navicella* as anomalous, had I not had an opportunity of comparing it with its ally *Neritina*, which has enabled me to explain its structure. In this genus, as in *Concholepas* and *Cryptostoma*, the mouth occupies so large a share of the cavity of the shell, and the hinder part of the foot of the animal is so short, that the operculum cannot be folded over in such a manner as to close the aperture. But instead of being very small, as in the two latter genera, the operculum is rather large in comparison with the size of the animal, and appears to serve a new purpose, viz. to separate the viscera from the upper surface of the foot, as the shelly plate does in the genus *Crepidula*. The part which projects externally is very small, and can only be compared to the flexible cartilaginous fringe on the edge of the outer whorls of the operculum of *Neritina*; whilst the shelly

part which is included in the body of the animal is four times the size of the external portion, and appears to represent the anterior margin and the two processes of the operculum of that genus, greatly developed. The anterior process, which appears to be analogous to the curved projection in *Neritina*, is produced into a straight lanceolate ridge, and the posterior into a rounded strongly serrated edge; the straightness of these processes evincing that this operculum does not revolve on its axis.

Other ovate spiral opercula of few volutions have a concentrically ridged inner surface, and their outer surface covered with a shelly coat, which varies in thickness in the different genera, being thin in *Nacca*, *Phasianella* and some *Cyclostomata*, and very thick and convex in the genera *Turbo* and *Imperator*. The disk to which these opercula are attached is like that of *Littorina*; but anterior to the muscle there is a very deep groove, into which the operculum can be pushed, and which probably covers the front part of it like a hood, when the animal is living. I have little doubt that this hood secretes the thick external shelly coat, which is quite out of the reach of the disk, and which increases in size, like the rest of the operculum, by the addition of shelly matter to the edge of its last whorls. That this is really the mode of growth of that part is proved by its being in many cases marked with spiral grooves; while in others the front part of the last whorl is of a different colour from the rest of the operculum, as though it had been covered from the light. It has been sometimes thought that such shelly opercula are attached to the animals by their convex sides; but this is not the case in any of the many specimens that I have examined, in which the opercula were naturally attached to the back of the animal. Some of them have the outer edge of their whorls dilated and free, and occasionally even elevated in such a manner as to form a spiral ridge on the outer side: a structure which may be seen fully developed in the very beautiful operculum of a West Indian *Cyclostoma* (*Cyclostoma mirabile*, of Wood's Supplement, t. 7. f. 22.).

The operculum of *Nerita* agrees in form with that of *Neritina*; but differs in having no cartilage on its edge, which is furnished, instead, with a groove; in its outer surface being covered with a thick variously formed shelly deposit, as in the genus *Turbo*; and in its inner surface being lined with a thick, callous, polished coat. Between the outer and inner coats there exists a very

distinct concentrically striated horny layer, like the operculum of *Littorina*; and the left muscular scar is deeply grooved, like that of the subannular opercula. This difference in the structure of their opercula forms an excellent distinctive character between these two genera; as do also the differences in the outer surface of those belonging to the genus *Nerita* between various species of that genus. Thus, for instance, the operculum of *N. polita* is smooth, with a transversely grooved marginal band; those of *N. exuvia*, *N. ornata* and *N. chlorostoma* are granular; and that of *N. peloronta* is smooth, with a broad convex marginal rib.

In the orbicular many-whorled opercula of the *Trochi*, the outside, which is generally concave, exhibits the volutions; and the inside is covered with a thick polished coat, marked with curved lines, produced by the successive enlargements of the muscular scar, radiating from the centre to the circumference.

An examination of the animal and operculum of *Trochus Pica* (which from its large size offers a good illustrative example of this form,) having enabled me to understand in what manner those opercula which appear to be the most complicated in their structure increase in size and thickness, I shall proceed to describe its mode of growth. A comparison with those of the other *Trochi* leaves little doubt that they are all formed and increase in size on the same principle.

The disk on the back of the foot of the animal to which the operculum is attached, shows three very distinct parts, viz. 1st, the muscle by which the operculum is affixed, which is semilunar, and occupies nearly the whole of the anterior half of the disk, having its hinder edge thin and membranaceous; 2ndly, an elongated triangular fleshy band, on the right side of its anterior part, which is separated from the muscle by a deep groove; and 3rdly, the back part of the foot, which is raised to the level of the muscle by an elevated border, attached in front to the membranes placed along the sides of the body of the animal, and is marked with minute concentric wrinkles, originating round a longitudinal fissure on its hinder edge, and becoming more and more transverse as they approach nearer to the muscle. This part of the disk merely forms a bed for the operculum to lie upon, without any attachment; it is semicircular, and is prolonged into a narrow process extending up the right

side of the triangular fleshy band. If the inner side of the operculum be examined, it will also be found to exhibit three parts, differing from each other in colour and surface, but agreeing exactly in form with the three parts described as found in the disk: 1st, the scar of the muscle, which is green, and occupies nearly the anterior half of the operculum: 2ndly, on the left of the scar (that is, when the operculum is turned with its inner side towards the observer,) a triangular pale brown spot, occupying the margin of the extremity, and a triangular portion of the last volution: and 3rdly, a black and polished posterior portion.

There can be no doubt, as these divisions of the operculum agree in shape with the three parts observed in the disk, that they are severally deposited by them; and on further examination it appears that the volutions are in fact formed of three coats, each deposited by one of these parts. The new layers are first added to the extremity of the whorls by the small triangular fleshy band placed on the right side of the muscle. Afterwards, as the operculum is moved round in order to present a new end to the influence of the fleshy band, the newly formed part is covered by a black coat, secreted by the process of the back of the foot which extends up the right side of the band. Both these layers are eventually covered by a green coat, which is deposited by the surface of the muscle, and the part of this latter coat which is left exposed as the operculum turns round on its axis, is again covered by a second thin black shining coat, deposited by the posterior part of the disk, or that which is formed of the elevated portion of the back of the foot.

That the spiral opercula actually revolve upon their axes is proved by the manner in which these coats are deposited, as well as by the circumstance that the front edge of the last volution is always directed towards the hinder part of the inner lip of the mouth of the shell,—a position which it could not constantly retain, in conformity with the manner in which these opercula enlarge, without undergoing this revolving motion. A convincing proof that the green coat of the muscular scar which occupies the outer edge of the front part of the penultimate, and the hinder part of the last whorl, has covered all parts of the operculum, except the front half of the last whorl, which in turning has not yet been brought under its influence, may be readily obtained by scratching off the thin black coat, when the green will be found beneath it in all parts

except that last referred to. The surface of the scar itself also demonstrates the fact of the revolution, its hinder edge being raised and definite ; while its front edge, which is progressive, is double, the posterior of the two portions being elevated, and the anterior, to which the muscle is just becoming attached, being thin and ill defined.

It has been often supposed that shells which have a toothed mouth never have any distinct operculum ; but the exceptions as regards annular or spiral opercula are numerous ; thus *Helicina aureola* and *H. depressa*, and all the *Polyodonta*, as *P. clangulus*, &c., have large and regular opercula.

The genus *Vermetus* has an orbicular horny concave operculum, like that of a *Trochus*, but differing in having a large, orbicular, irregularly grooved, muscular scar, placed in the centre instead of on the anterior side. The outer surface in some of the smaller species, as in *V. dentifer** and *V. Adansoni*, is furnished with very close spiral elevated laminae ; but in the large species, as *V. maximus*†, it is homogeneous and horny, and does not exhibit any of the volutions. I have no means of ascertaining whether these opercula revolve, but I am inclined to believe that the spiral ones most probably do.

To these, which every zoologist has been in the habit of regarding as opercula, but the structure of which has not previously been examined in detail, I am inclined to add two other bodies belonging to Ctenobranchous Molluscos animals, which have hitherto been generally regarded as anomalous. The first of these is the support, as it was called by its discoverer M. DE FRANCE, or under valve, as it has since been regarded by some English conchologists, of the genera *Capulus* and *Hipponyx*. I am induced to regard this body as analogous to the opercula of other spiral shells, because, on an attentive examination of the animals, I find that it is attached in the same situation, and not on the under side of the foot, as most conchologists have supposed ; the foot being folded on itself, and the walking disk of other Gasteropodes being in these animals (which never move from the place of their first attachment, and consequently require no such expansion,) represented by a few crumpled folds, placed between the part to which the shelly plate is attached and the head. In this idea I am further confirmed by a somewhat similar structure of the foot in the genus *Vermetus*, where the back of that organ represents a truncated cylinder, filling

* SOWERBY, Genera of Shells, Serpula, fig. 6.

† GRAY, Spicilegia Zoologica, tab. 5. fig. 3, a.

up and closing the mouth of the tubular shell. This foot is crowned by a horny operculum, and the walking disk is reduced to a narrow flat band, passing along the front of the cylinder, which band is in some species terminated by two conical processes, situated between that part and the base of the head: the processes have been described as tentacula, which they resemble in form. The shelly plate or operculum of *Capulus* is formed of concentric shelly laminae, with a nearly central nucleus, and differs from all other opercula at present known, in being immediately attached, by its outer surface, to other marine bodies, like the lower valves of the Oyster and of *Crania*, and thus forming the medium by which the animal is retained in its place. The mouth of the shell being nearly as large as the cavity, the adductor muscle, as in other shells of this form, is divided into two broad bands, forming a horseshoe-shaped, posterior, submarginal muscular scar, and the operculum is marked with a similar impression.

The second body to which I refer is the vesicular appendage, placed on the back of the hinder part of the foot of the animals belonging to the genus *Ianthina**, which appears to assist in floating the animal on the surface of the sea, and probably also in supporting the eggs after the death of the parent. This float, as it has been called, I am inclined, from its being situated in the same position as other opercula, to regard as analogous to those bodies in the neighbouring genera.

In the Medical Repository for 1821, I first called the attention of conchologists to the importance of the characters furnished by the operculum for the distinction of genera and families; and this subject, although almost neglected in this country, has since been pursued with great assiduity by M. DE BLAINVILLE and other French conchologists. I have fortunately had an opportunity of examining, either in the cabinet of the British Museum or in the Continental collections which I have visited, the animals of the greater number of genera of shells, and have been thereby enabled to determine that the form and structure

* CUVIER at the time of publishing his *Anatomy of Mollusca* appears to have entertained the same theory, for he there properly describes this body as attached to the hinder part of the foot, a little below the usual place of the operculum; but in his *Animal Kingdom* he seems to have abandoned it, and describes the animal as having no operculum, but having a vesicular organ under its foot.—*Règne Animal*, ed. 2. tom. iii. p. 84.

of their opercula offer some of the most constant characters for the distinction and arrangement of families and genera; while, on the other hand, I have convinced myself that systematists have been in the habit of placing too much reliance on the mere fact of their presence or absence as a family character, inasmuch as that circumstance alone will scarcely prove of generic importance. Thus in the genus *Voluta*, the animals of the eight or nine species which I have examined are all destitute of opercula, except *Voluta musica*, which has an operculum of moderate size. The Olives and Mitres are in the same predicament, most of the large species being destitute of opercula, while the smaller species of both genera are furnished with rather large ones, as may be easily seen in specimens of *Oliva eburnea*, *O. zonalis*, or *Mitra striatula*, in which the animals have been dried; and shells in this state are not uncommon in collections. The species of Cones offer in this respect the same variations. These observations will explain the apparent contradictions of describers, and the frequent controversies that have taken place as to whether these and some other genera have or have not opercula. That their presence or absence is not a family character may be inferred from all the genera of *Buccinidae* being provided with them except *Harpa* and *Dolium*. And this leads me to remark, that many genera and species which have very large mouths, in comparison with others of the family to which they belong, are destitute of, or have very small, opercula, whilst the others have moderate sized or even large ones. Thus the wide-mouthed Cones, as, for example, *Conus geographicus*, have no operculum, whilst the other species have a distinct one: and the genera *Cryptostoma* and *Concholepas* have very small opercula, in comparison with the size of their mouths, whilst the other genera allied to them have their opercula nearly as large as the mouths of their shells. The genus *Vermetus* is in this respect very remarkable: most of the species have the operculum as large as the mouth of the shell; but there is one in the British Museum which has an operculum very small in comparison to the size of the body of the animal, and not one fourth part of the diameter of the tube of shell. Some species of this genus, indeed, are described as having no operculum; and the observation of the above fact induces me to give credit to the description which I was at first inclined to doubt.

But of all the variations in this particular, those of *Capulus* and *Hipponyx*

are the most remarkable: some species appear always to have an operculum, which, like the under valve of *Crania*, differs in thickness according to the form and degree of exposure of the substance to which it is attached:—others, as the common *Capulus Hungaricus*, are generally without operculum, although, according to the observations of Dr. TURTON, the last-named species sometimes forms a thin support;—and there are others which, instead of forming an operculum, make for themselves (as has been already alluded to in this paper,) a cavity in the substance of the shell to which they are affixed, which is marked with a lunate ridge, corresponding with the muscular scar of the operculum, and doubtless occasioned by the attachment of the adductor muscle to that part of the shell, which is thus protected from the dissolving power of the mantle.

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1833.

A.

Acoustic figures, on, 593.

———— perfect resultant, 596 et seq.

———— imperfect resultant, 603.

———— of irregular plates, 604.

———— of plates of wood, 608.

Amphibia, anterior lymphatic hearts of, 92.

———— posterior lymphatic hearts of, 89.

Arsenates, phosphates and modifications of phosphoric acid, researches on, 253.

Atomic weights, experimental researches on, 523.

B.

Bakerian Lecture. Experimental determination of the laws of magneto-electric induction, &c., 95.

BARLOW (PETER, Esq.). An account of the construction of a fluid-lens refracting telescope of eight inches aperture, and eight feet and three quarters in length, made for the Royal Society by GEORGE DOLLOND, Esq., F.R.S., 1.

———— On the present situation of the magnetic lines of equal variation, and their changes on the terrestrial surface, 667.

Biphosphate of soda (second variety of), experiments on, 271.

———— (third variety of), experiments on, 273.

———— (fifth variety of), experiments on, 276.

BREWSTER (SIR DAVID, LL.D.). On the anatomical and optical structure of the crystalline lenses of animals, particularly that of the Cod, 323.

Bristol Channel and its rivers, tides of, 208.

C.

CHRISTIE (S. HUNTER, Esq.)—*The Bakerian Lecture*. Experimental determination of the laws of magneto-electric induction in different masses of the same metal, and of its intensity in different metals, 95.

————— On improvements in the instruments and methods employed in determining the direction and intensity of the terrestrial magnetic force, 343.

Colour, its influence on heat, general remarks on, 285.

————— *on the influence of, on heat and odours*, 285.

————— *its influence on the deposition of dew*, experiments on, 299.

————— *its influence on odours*, general remarks and experiments on, 300 et seq.

Comet of Encke, observations on, 549.

Conducting power generally, facts and observations respecting, 516.

Cotidal lines, essay towards a first approximation to a map of, 147.

————— as determined by the laws of fluids, 149.

————— effect of arms of the sea and bays on, 151.

————— effect of detached islands and groups of islands on, 152.

————— effects of the interference of undulations on, 154.

Crystalline lens of a Cod, number of fibres and teeth in, 329.

————— *lenses of animals, particularly that of the Cod*, on the anatomical and optical structure of, 323.

D.

DAUBENY (CHARLES, M.D.). Note on a paper by Dr. JOHN DAVY, entitled "Notice on the remains of the recent volcano in the Mediterranean," 545.

DAVY (JOHN, M.D.). Notice of the remains of the recent volcano in the Mediterranean, 143.

Dipping needle (Lieut. BARNETT'S) supported by a knife-edge, remarks on, 354.

Diurnal oscillations in the direction of a horizontal magnetic needle at Malta, on the, 243.

Diurnal variation in the intensity of the force soliciting a magnetic needle suspended horizontally at Malta, experiments on the, 241.

Dreaming, Dr. A. P. W. PHILIP'S observations on, 36.

E.

Electric conduction, general remarks and experiments on, 313.

————— on a new law of, 507.

Electricities derived from different sources, identity of, 23.

————— Table of the experimental effects common to, 48.

Electricity, common and voltaic, relation of, by measure, 48.

————— is identical in its nature, whatever be its source, 48.

Electricity by the induction of magnets, on a mode of obtaining an almost continuous current of, 320.

————— *excited in different metals*, on the intensity of, 133.

Electro-chemical decomposition, on, 675.

————— new conditions of, 676.

————— influence of water in, 681.

————— theory of, 682.

Electro-magnets, on certain peculiar properties of, 316.

Electro-magnetism and magneto-electricity, experimental researches in, 313.

Equivalent of lead, 524.

————— of chlorine; 529.

————— of silver, 536.

————— of barium, 537.

————— of nitrogen, 537.

————— of sulphur, 539.

————— of mercury, 540.

Error attributed to M. AMPERE, correction of, 53, *note*.

Establishments of places, meaning of, explained, 159.

Experimental researches in electricity (third series), 23.

————— (fourth series), 507.

————— (fifth series), 675.

Experiments (magnetic) on Vesuvius, Ætna, and at Gibraltar, 245.

F.

FARADAY (MICHAEL, Esq.). *Experimental researches in electricity*.—Third series, 23.

————— *Experimental researches in electricity*.—Fourth series, 507.

————— *Experimental researches in electricity*.—Fifth series, 675.

FIELD (Mr.), his experiments to determine if the action of the heart be affected by agents making their impressions on the ganglions and plexuses of nerves, 60.

Filters, remarks on the employment of, in chemical analyses, 541.

FISHER (Rev. G.). *Magnetical experiments*, made principally in the South part of Europe and in Asia Minor, during the years 1827-1832, 237.

Frith of Forth, and its rivers, tides of, 209.

G.

Professor GAUSS, *his method for determining the terrestrial magnetic intensity*, remarks on, 357.

Glisson's capsule, &c., of the vaginal portion of, 723.

————— of the interlobular portion of, 729.

GRAHAM (T., Esq.). *Researches on the arseniates, phosphates, and modifications of phosphoric acid*, 253.

GRAY, (JOHN EDW. Esq.). Some observations on the economy of molluscous animals, and on the structure of their shells, 771.

H.

HALL (MARSHALL, M.D.). On the reflex function of the medulla oblongata and medulla spinalis, 635.

Hearts, four distinct lymphatic, in certain amphibious animals, on the existence of, 89.

Heat, on the absorption of, by differently coloured substances, experiments on, 287.

——— *on the radiation of, by differently coloured substances, experiments on, 291.*

HENDERSON (THOMAS, Esq.). Observations on the comet of Encke, made in June 1832, 549.

Hepatic veins, &c., of the, 733.

HERSCHEL (Sir J. F. W.). Observations of nebulae and clusters of stars, made at Slough, with a twenty-feet reflector, between the years 1825 and 1833, 359.

I.

IVORY (JAMES, K.H.). On the development of the disturbing function, upon which depend the inequalities of the motions of the planets, caused by their mutual attraction, 559.

K.

KIERNAN (FRANCIS, Esq.). The anatomy and physiology of the liver, 711.

L.

Liver, the anatomy and physiology of, 711.

——— *of the lobules of, 713.*

——— *of the surfaces of, 717.*

——— *of the portal canals of, 720.*

——— *of the lobular venous plexuses of, 744.*

——— *of the lobular arteries of, 747.*

——— *of the cortical and medullary substances of FERREIN, and of the appearances produced by congestion, 749.*

LUBBOCK (JOHN WILLIAM, Esq.). Note on the tides, 19.

M.

Magnetic forces soliciting a horizontal magnetic needle, experiments to determine the relative, 237.

Magnetic lines of equal variation, on the present situation of, and their changes on the terrestrial surface, 667.

Magnetic powers of soft iron, on the, 333.

Magnetical experiments, made principally in the South of Europe and in Asia Minor, during the years 1827–1832, 237.

Magnetism of soft iron, under the immediate inductive influence of an electric current, eminently useful in the formation of artificial magnets, 340.

Magneto-electric induction, experimental determination of the laws of, in different masses of the same metal, and of its intensity in different metals, 95.

Magneto-electric intensity, in different masses of the same metal, on the law of variation of, 101.

————— in different lengths of the same wire, *ibid.*

————— in wires of different diameters, 120.

Mars, on the extensive atmosphere of, 15.

Medulla oblongata and medulla spinalis, on the reflex function of, 635.

Metaphosphate of barytes, experiments on, 278.

————— of lime, experiments on, 280.

Mollusca, of the power they possess to dissolve shells, rocks, &c., 796.

————— on the deposition of shelly matter by the foot of, 805.

Molluscous animals, some observations on, and on the structure of their shells, 771.

Motions of the planets, on the development of the disturbing function, upon which their inequalities, caused by their mutual attraction, depend, 559.

MÜLLER (JOHN, M.D.). On the existence of four distinct hearts, having regular pulsations, connected with the lymphatic system, in certain amphibious animals, 89.

N.

Nebulae and clusters of stars, observations of, made at Slough with a twenty-feet reflector between the years 1825 and 1833, 359.

————— Tables of observations of, 365–481.

Nervous and muscular systems in the more perfect animals, on the relation which subsists between them, 55.

North magnetic pole, its position as determined by Captain ROSS and Commander JAMES ROSS, coincides with the common point of intersection of Mr. BARLOW's curves of equal variation, 673.

P.

PHILIP (A. P. W., M.D.). On the relation which subsists between the nervous and muscular systems in the more perfect animals, and the nature of the influence by which it is maintained, 55.

————— On the nature of sleep, 73.

Phosphates and pyrophosphates, of the neutral, 267.

Phosphoric acid, of the modifications of, 280.

- Ports, establishment of*, meaning of the term explained, 19.
 ————— of Brest, Plymouth, Portsmouth, Sheerness, and London Docks, 21.
 ————— of St. Helena, 22.

R.

- Recent volcano in the Mediterranean*, Note on Dr. JOHN DAVY's paper on, 545.
 RITCHIE (Rev. WILLIAM, LL.D.). Experimental researches in electro-magnetism and magneto-electricity, 313.
River and Gulf of St. Lawrence, tides of, 210.
River Elbe, tides of, 210.
 ——— *Gironde*, tides of, 210.
 ——— *Thames*, tides of, 208.
 ——— *tides*, magnitude of, 208.
 ——— ——— the bore in, 205.
 ——— *Waveney*, tides of, 209.
 ——— *Weser*, tides of, 210.
Rivers, high and low water in, 205.
 ——— velocity of the tide-wave in, 207.
 Ross (Captain), his return noticed, 673.

S.

- Shells*, first formation of, 771.
 ——— on the operculum of, 806.
 ——— the structure of, 789.
 ——— their external form and variations, 774.
Sleep, on the nature of, 73.
Soda, biphosphate of, experiments on, 270.
Soft iron horse-shoe magnet, account of one that had been made nearly six months, which supported a weight of 100lbs., 337.
Soft iron horse-shoe magnetized by an electric current, experiments to determine the weight it could support, with from one to fifteen thin plates of mica interposed between the poles and the keeper, 339.
 SOUTH (Sir JAMES). On the extensive atmosphere of Mars, 15.
 STARK (JAMES, M.D.) On the influence of colour on heat and odours, 285.
Subarsenate and subphosphate of barytes, experiments on, 264.
 ————— *lead*, experiments on, 266.
 ————— *lime*, experiments on, 265.
 ————— *soda*, experiments on, 253.
Subphosphates and subarsenate of potash, experiments on, 263.
Sulphuret of carbon and crown glass, dispersive ratio of, 6.

T.

Telescope (fluid-lens refracting), account of the construction of, 1.

————— general principle adopted in the construction of, 5.

————— equations to determine the curvature of the lenses of, 6.

Terrestrial magnetic force, on improvements in the instruments and methods employed in determining the direction and intensity of, 343.

Tide observations, causes of inaccuracy in, arise from :—

1. Difference between the time of high water and slack water, 156.
2. Change of the moon's angular distance from the sun in the course of the day, 159.
3. The semimenstrual inequality of the establishment, 161.
4. The correction of the establishment for the age of the tide, 162.

————— *now extant*, discussion of, 164.

————— suggestions for making them in future, viz. :—

1. Of the observation of the height and time of tides, 227.
2. On finding the establishment of any place by observation, 228.
3. On the effects of the age of the tide, 231.
4. On the mode of reducing tide observations, 231.
5. On tracing the motion of the tide-wave by comparative observations, 233.

Tides, (derivative,) 150.

————— general remarks on the course of, viz. :—

1. On the velocity of the tide-wave, 211.
2. On the form of the cotidal lines, 213.
3. On tide-currents running alternately in two opposite directions,—and revolving tide-currents, 215.
4. On the magnitude of tides, 217.
5. On the constancy of cotidal lines, 219.
6. On some peculiarities of the tides, viz. :—
 Difference of the two diurnal tides, 221.
 Single day tides, 224.
 Double half-day tides, 226.

————— note on the, 19.

————— *of rivers*, on, 203.

————— *of St. George's Channel*, 179.

————— *of the Arctic Ocean*, 184.

————— *of the Atlantic Islands*, notice of some anomalies pertaining to, 173.

————— *of the British Channel*, 176.

————— *of the coasts of Australia*, 197.

————— *of the Indian Ocean*, 200.

————— *of the North Sea*, 175.

MDCCCXXXIII.

5 0

Tides of the Pacific, on the, viz :—

1. Western coast of America, 192.
2. Central parts of the Pacific, 195.
3. Western parts of the Pacific, 196.

— *of the South Atlantic*, 189.

— *on the east coast of the Atlantic*, considered, 169.

— *on the east coast of Great Britain*, 185.

— *of the West of Ireland*, 181.

— *on a globe covered with water*, 149.

— *of the west coast of the Atlantic*, considered, 169.

— *on the west coast of Scotland*, 183.

— *on the coast of the German Ocean*, 186.

TURNER (EDWARD, M.D.). Experimental researches on atomic weights, 523.

V.

Voltaic battery, observations on the, so called, poles of, 708.

Volcano in the Mediterranean, notice of the remains of the recent, 143.

W.

WATKINS (MR. FRANCIS). On the magnetic powers of soft iron, 333.

WHEATSTONE (CHARLES, ESQ.). On the figures obtained by strewing sand on vibrating surfaces, commonly called acoustic figures, 593.

WHEWELL (REV. W.). Essay towards a first approximation to a map of cotidal lines, 147.

LONDON:

PRINTED BY RICHARD TAYLOR,

RED LION COURT, FLEET STREET.

METEOROLOGICAL JOURNAL,

KEPT BY THE ASSISTANT SECRETARY

AT THE APARTMENTS OF THE

R O Y A L S O C I E T Y,

BY ORDER OF

THE PRESIDENT AND COUNCIL.

MDCCCXXXIV.

u

METEOROLOGICAL JOURNAL FOR JULY, 1833.

1833. July.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in de- grees of Fahr.	External Thermometer.				Rain, in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
1	29.869	75.5	29.835	69.9	47	62.2	61.6	53.7	66.6	0.050	SW	{ A.M. Fine and clear. P.M. Heavy thun- der showers, with hail and brisk wind. Fine and clear—light clouds.—Even- ing, very calm.
2	29.953	72.4	29.968	68.7	47	61.2	65.0	47.3	67.0	0.272	W	
3	30.041	69.8	30.071	68.2	47	63.2	64.3	50.2	66.7		W	
4	30.204	73.6	30.174	70.2	48	65.8	72.7	51.7	73.7	0.094	SSW	Fine.—A.M. Cloudless. P.M. Cloudy.
5	30.171	67.3	30.095	70.4	56	63.9	71.0	56.6	73.3	0.011	SSW	Fine—lightly cloudy.
6	29.867	68.7	29.775	70.4	55	68.9	71.5	55.3	73.8		E	{ Fine.—A.M. Light high clouds. P.M. Cloudless.
7	29.657	68.7	29.697	70.9	56	67.5	67.8	61.3	69.7		E	Lightly overcast.—Light rain, P.M.
8	29.827	66.2	29.893	68.7	57	61.6	66.2	58.3	68.6	0.105	W	{ Overcast—showery.—Light breeze at night.
9	30.116	65.2	30.120	68.4	52	60.2	63.7	54.8	65.8	0.400	N	{ Cloudy—light unsteady airs.—Evening, fine and clear.
10	30.053	70.7	29.991	70.3	55	65.0	73.2	52.7	73.4		NNW	Fine—lightly cloudy.
11	29.950	68.6	29.932	71.3	60	64.5	68.0	57.6	71.9		NNW	{ Lightly cloudy and overcast.—Light shower, P.M.
12	29.867	65.3	29.838	67.0	53	58.5	63.6	55.6	64.5		E	Overcast—light wind.
13	29.933	62.4	29.970	66.0	51	56.7	61.1	52.9	61.7		N	Overcast—light wind.
14	30.012	65.6	29.968	66.7	53	59.8	65.2	55.2	70.4		N	Overcast.
15	30.031	73.0	30.073	68.9	56	63.0	69.7	58.2	71.4		SE	{ A.M. Cloudy. P.M. Fine—light clouds and wind.
16	30.232	72.3	30.223	70.7	54	65.2	73.6	56.0	74.2		N	Fine and cloudless.
17	30.241	71.6	30.220	73.2	62	69.0	78.0	58.6	80.4		SW	A.M. Fine. P.M. Cloudy.
18	30.184	71.0	30.109	74.5	61	70.5	78.4	63.7	80.4		S	Lightly cloudy.—Fine, P.M.
19	29.905	71.1	29.802	73.2	58	66.5	70.6	62.8	74.8		SW	A.M. Fine. P.M. Heavy rain at 2½ h.
20	29.665	73.2	29.660	73.6	58	67.2	68.0	60.0	71.4		SW	Cloudy.—Light wind and rain, P.M.
21	29.778	70.6	29.821	70.7	53	62.1	64.4	53.3	66.3	0.092	W	A.M. Cloudy. P.M. Fine and clear.
22	29.827	65.7	29.693	68.6	58	59.0	67.8	52.2	69.7	0.161	SSW	{ A.M. Rain. P.M. Cloudy.—Evening, fine.
23	29.769	68.6	29.682	69.8	57	63.9	62.1	57.2	70.7	0.200	WSW	{ Overcast.—Heavy shower, P.M.—Evening clear.
24	30.065	70.7	30.108	69.6	50	63.3	67.2	51.4	67.8	0.297	NNW	Fine and clear—light clouds.
25	30.207	67.8	30.207	69.8	57	63.1	70.2	53.1	71.8		SW	Overcast.—Evening, fine and clear.
26	30.339	71.2	30.279	70.7	50	65.2	73.9	53.3	76.3		WSW	Fine and nearly cloudless.
27	30.301	72.4	30.283	73.9	63	71.4	79.6	63.2	80.5		W	{ Fine.—A.M. Light high clouds. P.M. Nearly cloudless.
28	30.326	73.9	30.301	75.6	64	71.7	75.3	64.7	78.4		NNE	A.M. Overcast. P.M. Fine and clear.
29	30.247	73.6	30.324	75.1	59	67.3	74.3	58.7	75.7		E	{ A.M. Light soft clouds. P.M. Clear and cloudless—light breeze.
30	30.461	70.4	30.455	73.0	58	61.0	67.2	56.3	70.7		N	Overcast—light wind.—Evening, clear.
31	30.434	66.2	30.366	70.6	54	59.6	68.6	52.3	68.8		NNE	Fine—lightly cloudy.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	30.056	69.8	30.033	70.6	55.0	64.1	69.2	56.1	71.5	1.682		

Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr. { 9 A.M. 29.942 3 P.M. 29.916 }

OBSERVANDA.

Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge..... = 83 feet 2½ in.
above the mean level of the Sea (presumed about) = 95 feet.

The External Thermometer is 2 feet higher than the Barometer Cistern.

Height of the Receiver of the Rain Gauge above the Court of Somerset House..... = 79 feet.

The hours of observation are of Mean Time, the day beginning at Midnight.

The Thermometers are graduated by Fahrenheit's Scale.

The Barometer is divided into inches and decimals.

METEOROLOGICAL JOURNAL FOR AUGUST, 1833.

1833. August.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in de- grees of Fahr.	External Thermometer.				Rain, in Inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
1	30.392	65.7	30.404	70.2	50	61.4	65.3	57.3	66.4		NNE	Cloudy—light wind.
2	30.378	63.3	30.352	67.2	54	57.6	63.3	53.5	64.5		NNE	{ Overcast—light wind.—Light rain early A.M.
3	30.301	63.3	30.314	67.4	54	60.0	64.2	54.8	64.7		N	Cloudy—light wind.
4	30.366	66.3	30.297	66.9	43	59.4	65.1	48.7	68.2		N	Fine and clear—light clouds.
5	30.111	64.4	30.087	68.0	51	63.0	67.4	51.7	68.2		NNW	{ A.M. Lightly cloudy. P.M. Fine and clear.—Shower at night.
6	30.172	66.3	30.150	67.4	47	58.8	65.3	49.4	66.7		NNE	Fine and clear—light clouds.
7	30.141	64.5	30.084	66.8	45	58.4	66.6	48.3	68.7		N	{ Fine.—A.M. Nearly cloudless. P.M. Cloudy—light wind.
8	30.091	66.3	30.071	67.6	50	62.2	67.2	52.8	69.7		W	{ A.M. Fine and cloudless. P.M. Cloudy Evening, lightly cloudy—calm.
9	30.063	67.3	30.012	68.8	53	65.8	69.5	58.6	73.7		SSW	{ A.M. Fine—nearly cloudless. P.M. Lightly overcast.
10	30.031	67.3	29.978	69.7	55	63.8	70.5	55.2	73.6		W	{ Fine—light broken clouds.—Heavy rain at 6 P.M.
11	30.002	67.3	30.030	69.8	58	63.7	67.7	51.3	70.0	0.078	WSW	Fine—lightly cloudy.
12	30.210	66.2	30.154	68.7	49	59.7	67.0	49.8	68.2		W	Fine—light clouds—calm.
13	29.827	62.8	29.728	66.8	51	57.1	64.2	52.7	65.5		WNW	Overcast.
14	29.649	63.4	29.675	66.6	51	59.0	63.8	50.7	65.3	0.008	NNE	Fair—lightly cloudy.
15	29.768	62.2	29.760	65.8	52	59.3	65.2	50.2	66.3		N	A.M. Fine. P.M. Lightly overcast.
16	29.794	64.4	29.838	66.5	46	61.2	65.6	52.2	65.3		SSW	A.M. Cloudy. P.M. Fine.
17	29.918	64.3	29.848	66.4	49	60.2	67.3	50.6	69.9		SSW	A.M. Fine. P.M. Cloudy.
18	29.827	62.5	29.836	66.4	51	59.3	65.2	52.6	69.6		SW	A.M. Fine. P.M. Rain.
19	29.833	65.4	29.875	67.7	56	64.0	68.3	57.7	69.4	0.204	WSW	Fine—light clouds.
20	29.986	66.4	29.934	68.9	50	62.7	70.2	54.5	71.7		SW	Fine—lightly cloudy.
21	29.899	66.3	29.794	69.9	55	64.5	72.6	61.8	75.5		SW	{ A.M. Lightly overcast. P.M. Fine— light clouds.
22	29.782	67.8	29.722	69.1	47	60.3	67.8	52.0	68.6		SW	Fine—nearly cloudless.
23	29.658	66.6	29.707	68.8	48	61.1	67.8	51.0	68.3		SW var.	Fine—light clouds and wind.
24	29.964	64.2	29.990	68.2	53	61.3	68.7	54.2	69.4		W	Fine—lightly cloudy.
25	30.126	60.4	30.196	67.3	52	59.9	61.8	53.3	64.5		NE var.	A.M. Fine. P.M. Cloudy.
26	30.303	61.8	30.259	66.2	51	57.5	67.2	54.0	68.2		NW	A.M. Lightly overcast. P.M. Fine.
27	30.255	64.2	30.194	66.7	51	58.3	69.5	50.4	71.5		SW	Fine and cloudless—light wind.
28	30.237	65.7	30.225	68.9	54	63.2	72.8	53.0	73.7		SSW	Fine—light clouds.
29	30.159	67.4	30.010	69.6	59	61.5	72.8	55.3	75.3		S	{ Fine.—A.M. Light clouds. P.M. Cloudless.
30	29.893	66.7	29.713	69.0	52	61.3	66.2	56.4	68.2		SW	{ A.M. Cloudless. P.M. From 6½ h. rain and high wind.
31	28.970	61.2	29.011	60.3	51	52.5	50.9	48.2	52.5	0.277	SW var.	Light rain, with high wind.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	30.004	64.9	29.976	67.7	51.2	60.6	66.7	53.0	68.4	0.567		

Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr. { 9 A.M. 3 P.M. }
 { 29.904 29.867 }

OBSERVANDA.

Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge = 83 feet 2½ in.

..... above the mean level of the Sea (presumed about) = 95 feet.

The External Thermometer is 2 feet higher than the Barometer Cistern.

Height of the Receiver of the Rain Gauge above the Court of Somerset House = 79 feet.

The hours of observation are of Mean Time, the day beginning at Midnight.

The Thermometers are graduated by Fahrenheit's Scale.

The Barometer is divided into inches and decimals.

METEOROLOGICAL JOURNAL FOR SEPTEMBER, 1833.

1833. Sept.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in degrees of Fahr.	External Thermometer.				Rain, in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
○ 1	29.467	57.5	29.598	59.8	41	51.3	55.0	48.0	55.3	0.113	ESE	Fine—lightly cloudy.
▷ 2	29.958	55.8	29.950	59.7	39	50.2	60.2	41.0	61.9	0.113	SW	{ Fine.—A.M. Cloudless. P.M. Light clouds.
♂ 3	29.707	58.5	29.610	59.8	53	56.6	57.9	49.8	61.2		SSW	{ Fine—light clouds.—Heavy rain at 1½ P.M.
♀ 4	29.944	57.2	30.056	59.3	45	54.0	57.4	47.2	58.6		NE var.	Fine—light clouds and wind.
⌞ 5	30.305	54.7	30.299	58.4	45	52.3	59.7	43.0	59.3	0.025	NNE	{ Fine—light wind.—A.M. Nearly cloudless. P.M. Light clouds.
♀ 6	30.281	56.2	30.181	59.9	49	54.9	62.8	45.4	63.2		NE var.	{ Fine—light wind.—A.M. Light clouds. P.M. Cloudless.
h 7	30.059	57.0	29.996	62.5	53	57.4	66.0	49.6	67.2		NE var.	Fine—lightly cloudy.
○ 8	29.816	58.0	29.804	61.9	52	55.2	61.8	52.9	62.8	0.185	SE var.	{ Overcast—light wind.—Light rain, A.M.
▷ 9	29.899	59.8	30.027	63.2	55	57.9	64.3	54.8	64.8		NNW	{ A.M. Lightly overcast. P.M. Fine—light clouds.
♂ 10	30.063	60.7	30.027	61.5	53	57.6	59.8	56.4	60.2		ENE	Lightly cloudy and overcast.
♀ 11	29.792	60.7	29.703	64.5	56	58.7	65.2	55.8	66.8	0.041	NNW	{ A.M. Overcast—very light rain. P.M. Fine—light clouds.
⌞ 12	29.973	59.8	30.033	62.0	45	55.5	60.3	48.2	61.2		SSW	A.M. Cloudy. P.M. Fine.
● ♀ 13	30.146	57.2	30.097	61.6	43	52.9	61.0	43.0	62.4		SW	{ Fine.—A.M. Nearly cloudless. P.M. Light clouds.
h 14	29.922	59.6	29.901	63.5	51	59.4	65.7	52.2	66.3	0.185	NE var.	A.M. Fine. P.M. Cloudy.
○ 15	29.942	58.8	29.903	62.5	50	53.0	63.8	46.0	64.7		SSW	Fine—nearly cloudless.
▷ 16	29.639	61.0	29.641	63.4	52	58.2	62.0	52.4	64.4		SW	{ A.M. Fine. P.M. Cloudy.—At night, rain.
♂ 17	29.530	59.7	29.623	63.3	53	56.4	62.6	52.8	63.5	0.185	ENE	Cloudy.—Light rain, early A.M.
♀ 18	29.778	58.7	29.812	62.3	52	54.3	59.6	47.5	62.2		SW	Fine—light clouds.
⌞ 19	30.043	57.7	30.081	61.4	48	53.8	59.2	45.5	61.7		SW	A.M. Fine. P.M. Light rain.
♀ 20	30.253	56.0	30.235	60.0	50	50.6	60.6	45.0	61.2	0.041	ENE	A.M. Fine. P.M. Lightly cloudy.
h 21	30.188	57.3	30.107	60.7	50	52.8	61.6	49.9	63.2		E	A.M. Light fog. P.M. Fine.
▷ 22	30.053	57.6	29.990	61.5	49	53.2	62.6	50.0	63.7		E	A.M. Fog. P.M. Fine—light clouds.
▷ 23	29.877	58.8	29.808	63.6	53	56.2	63.2	51.4	64.6	0.041	ESE	Fine—light haze and clouds.
♂ 24	29.443	60.2	29.415	62.0	55	59.6	61.2	53.2	61.5		NW var.	{ Overcast—light rain and brisk wind.—At night, high wind.
♀ 25	29.707	61.7	29.754	63.9	52	59.9	62.4	55.0	64.5		S	Fine—nearly cloudless—brisk wind.
⌞ 26	29.798	61.2	29.839	64.2	54	59.0	61.5	54.2	63.7	0.041	S	Fine—nearly cloudless.
♀ 27	29.895	57.7	29.819	61.6	46	49.9	61.0	46.0	61.5		SSW	A.M. Fog. P.M. Fine.
○ h 28	29.609	59.7	29.581	61.7	57	57.4	58.4	49.4	59.3		ESE	A.M. Cloudy. P.M. Fair.
○ 29	29.934	57.7	30.010	61.3	53	52.6	60.6	46.3	61.5	0.041	WSW	{ A.M. Fine and cloudless. P.M. Lightly cloudy.
▷ 30	30.254	57.3	30.260	60.7	50	50.7	61.7	48.8	62.3		ESE	A.M. Fog. P.M. Fine—light clouds.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	29.912	58.5	29.905	61.7	50.1	55.1	61.3	49.4	62.5	0.477		

Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr..... { 9 A.M. 29.830 3 P.M. 29.813 }

OBSERVANDA.

Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge = 83 feet 2½ in.
 ————— above the mean level of the Sea (presumed about)..... = 95 feet.

The External Thermometer is 2 feet higher than the Barometer Cistern.

Height of the Receiver of the Rain Gauge above the Court of Somerset House = 79 feet.

The hours of observation are of Mean Time, the day beginning at Midnight.

The Thermometers are graduated by Fahrenheit's Scale.

The Barometer is divided into inches and decimals.

METEOROLOGICAL JOURNAL FOR OCTOBER, 1833.

1833. October.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in de- grees of Fahr.	External Thermometer.				Rain, in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
♂ 1	30.303	55.7	30.264	57.7	45	47.7	55.8	45.3	56.7		E	{ A.M. Fog. P.M. Fine—light clouds and haze.
♀ 2	30.239	55.3	30.154	58.4	47	48.2	60.3	46.8	60.3		E	{ A.M. Light fog. P.M. Fine—light clouds and wind.
♂ 3	30.063	56.2	30.039	57.4	51	51.8	55.2	47.7	55.1		NNE	Haze.
♀ 4	30.142	55.2	30.106	58.8	51	51.3	59.6	45.6	60.4		NNE	{ Fine.—A.M. Cloudless. P.M. Light clouds.
h 5	30.119	54.7	30.122	58.6	52	52.2	58.4	45.5	58.8		NNE	Lightly cloudy and overcast.
⊙ 6	30.149	55.7	30.126	58.7	53	53.4	60.7	49.3	61.3		NNE	{ A.M. Overcast. P.M. Fine—light clouds.
♂ 7	30.158	55.2	30.095	58.4	51	50.9	59.7	48.3	59.7		NNE	{ A.M. Overcast. P.M. Fine and clear—light clouds and wind.
♂ 8	30.032	55.4	29.990	58.7	53	52.7	60.7	47.6	60.8		NNE	{ A.M. Light fog. P.M. Fine—light clouds.
♀ 9	30.166	55.3	30.202	58.3	51	51.0	57.4	48.3	57.4		NNE	Lightly cloudy and overcast—light wind.
♂ 10	30.243	54.9	30.170	57.4	49	53.5	55.7	47.5	56.5		E	Fine and cloudless.
♀ 11	29.994	52.7	29.948	56.4	43	47.2	57.2	43.7	58.3		E	{ A.M. Fog. P.M. Fair—lightly over- cast.
h 12	29.950	54.3	29.871	57.8	50	50.6	58.2	46.7	58.8		WSW	Lightly overcast.—Evening, light rain.
⊙ 13	30.109	51.0	30.039	55.3	41	43.8	51.9	38.6	57.6		WSW	{ A.M. Fine and cloudless. P.M. Fair—lightly cloudy.
♂ 14	29.540	55.8	29.478	58.6	57	57.7	57.7	43.3	59.7	0.014	SSW	Rain.
♂ 15	29.225	55.3	29.128	57.6	44	49.7	53.7	47.8	54.3	0.014	SW	{ Fine and clear—light clouds.—Even- ing, light rain.
♀ 16	29.215	51.8	29.294	53.8	45	45.4	50.3	41.3	50.3	0.017	W	{ Lightly cloudy.—At noon, fine and clear: evening, light rain.
♂ 17	29.556	51.4	29.633	53.7	49	49.1	51.7	43.2	52.6	0.028	NW	A.M. Light rain. P.M. Overcast.
♀ 18	29.668	50.3	29.547	53.3	43	45.7	51.2	41.2	51.2	0.008	W	{ Lightly cloudy and hazy.—Light wind, A.M.
h 19	29.433	50.9	29.893	54.2	47	47.8	51.3	42.8	53.3	0.031	W	Fine—lightly cloudy.
⊙ 20	29.572	48.6	29.715	52.3	41	41.7	50.8	38.3	55.5	0.008	W	{ Fine—haze.—A.M. Cloudless. P.M. Light clouds and wind.
♂ 21	29.671	52.3	29.627	55.4	55	55.8	57.7	41.2	57.7		S var.	{ Overcast.—At night, rain with strong wind.
♂ 22	29.677	57.3	29.692	60.3	56	56.0	59.3	54.8	60.7	0.028	SSW	{ Fair—lightly overcast.—At night, rain with strong brisk wind.
♀ 23	29.430	57.6	29.507	59.9	55	56.9	56.6	53.2	59.3	0.014	S	Light wind and broken clouds.
♂ 24	29.686	55.7	29.576	59.6	52	53.3	61.8	47.3	61.7	0.008	ESE	{ A.M. Lightly cloudy. P.M. Light clouds and wind.
♀ 25	29.470	58.3	29.428	60.6	53	55.9	60.5	53.3	61.7		E	{ Fine—light high clouds.—Evening, cloudless.
h 26	29.567	58.9	29.522	61.2	54	56.0	60.9	54.7	62.3		ESE	{ A.M. Fine and clear. P.M. Overcast. Evening, light rain.
⊙ 27	29.875	57.7	29.847	60.7	51	52.1	59.3	48.8	59.4	0.006	ESE	{ A.M. Haze. P.M. Fine—light soc- culous clouds—light unsteady wind.
⊙ 28	29.776	59.2	29.744	61.6	56	56.5	60.5	51.8	60.5		E	{ A.M. Light fog and deposition. P.M. Fine.
♂ 29	29.739	58.8	29.878	61.9	55	55.8	62.3	52.7	62.3		E	Fine—nearly cloudless.—Haze, A.M.
♀ 30	30.011	58.3	30.008	60.4	52	52.6	60.7	49.7	61.3		E	A.M. Haze. P.M. Fine and cloudless.
h 31	30.071	56.4	29.999	58.4	48	48.2	54.5	47.2	56.7		W	Fog.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	29.834	55.0	29.827	57.9	50.0	51.3	57.1	46.9	58.1	0.176		

Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr. { 9 A.M. 29.762 3 P.M. 29.746 }

OBSERVANDA.

Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge..... = 83 feet 2½ in.
above the mean level of the Sea (presumed about) = 95 feet.

The External Thermometer is 2 feet higher than the Barometer Cistern.

Height of the Receiver of the Rain Gauge above the Court of Somerset House = 79 feet.

The hours of observation are of Mean Time, the day beginning at Midnight.

The Thermometers are graduated by Fahrenheit's Scale.

The Barometer is divided into inches and decimals.

METEOROLOGICAL JOURNAL FOR NOVEMBER, 1833.

1833. Nov.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in degrees of Fahr.	External Thermometer.				Rain, in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
♀ 1	29.840	58.3	29.841	60.3	57	57.3	58.2	47.7	59.7	0.007	WSW	{ A.M. Rain, early. P.M. Fine and cloudless.
h 2	30.056	55.4	29.804	58.3	47	49.0	55.2	45.3	56.3	0.008	WSW	{ A.M. Lightly cloudy. P.M. Fine.
○ 3	29.721	54.7	29.858	55.7	41	48.8	51.6	45.8	51.6		WNW	{ A.M. Fine and cloudless—light brisk wind. P.M. Cloudy.
▷ 4	30.135	49.8	30.144	52.4	38	40.8	48.2	37.3	49.2		WSW	{ Fine.—A.M. Nearly cloudless. P.M. Light clouds.
♂ 5	30.284	48.7	30.134	51.0	41	44.5	50.3	37.3	53.7		WSW	Overcast.—Light rain, P.M.
♀ 6	30.004	53.7	29.990	57.6	52	54.6	55.8	43.7	57.4		WSW	Overcast and cloudy—light wind.
♂ 7	29.853	51.9	29.501	51.7	43	46.8	43.6	43.6	46.8		WSW	Rain.—Dark and lowering, P.M.
♀ 8	29.695	46.6	29.819	48.4	36	38.7	44.7	35.5	44.7	0.556	NNW	Fine—light clouds.
h 9	29.998	45.9	30.053	47.4	38	39.7	42.9	37.2	45.8	0.008	WSW	A.M. Haze. P.M. Fine—light clouds.
○ 10	30.122	47.3	30.110	49.7	43	46.9	51.1	37.8	51.1		SSW	Lightly cloudy and overcast—light airs.
● ▷ 11	30.076	50.3	30.053	51.5	45	48.6	50.2	46.4	50.7		S	Overcast.—Light rain, P.M.
♂ 12	30.223	49.7	30.224	51.2	42	40.7	45.9	41.3	45.9		SW	Strong fog.
♀ 13	30.303	49.4	30.263	50.4	45	45.1	47.0	40.3	47.0		SW	Lightly overcast and hazy.
♂ 14	30.158	45.3	30.122	46.6	38	38.2	42.1	35.2	42.1		NE	Fine—light haze.—Cloudless, A.M.
♀ 15	30.071	44.4	29.976	44.9	35	37.8	40.3	36.3	40.3		E	Overcast—light fog.
h 16	29.874	44.8	29.867	47.2	38	41.3	45.0	37.4	45.7		S	{ Lightly cloudy—haze.—Light rain at night.
○ 17	29.986	46.7	30.036	50.0	44	47.2	51.9	40.7	52.4		SSW	{ A.M. Cloudless—fog—deposition. P.M. Lightly cloudy.
▷ 18	30.291	50.6	30.293	52.0	48	50.3	52.7	46.4	52.7		ESE	{ Overcast.—Light fog and deposition, A.M.
♂ 19	30.251	52.7	30.198	53.8	49	49.7	50.2	49.2	50.3		W	Overcast—light fog.
♀ 20	30.109	49.1	30.057	51.3	40	40.8	46.3	40.3	48.7		SW	{ Light fog.—A.M. Overcast. P.M. Cloudless.
♂ 21	30.057	51.2	29.964	52.5	45	45.6	49.7	40.7	53.7		W	Lightly cloudy.—Light fog, A.M.
♀ 22	29.647	53.7	29.469	55.2	52	53.7	54.8	45.0	54.8		SSW	Cloudy—light wind.
h 23	29.723	51.8	29.724	53.3	44	45.3	48.4	43.7	48.4		WSW	A.M. Lightly overcast. P.M. Fine.
○ 24	29.604	49.8	29.519	51.2	45	45.8	48.1	40.5	48.4		SSW	{ A.M. Fine and clear—light cloudiness. P.M. Dark—showery.
▷ 25	29.691	46.7	29.788	47.5	36	38.1	42.6	36.5	42.6	0.122	WSW	{ A.M. Cloudless—light fog and deposition. P.M. Lightly cloudy.
♂ 26	30.155	43.3	30.134	44.9	31	34.1	40.3	31.6	41.4	0.067	SSW	{ A.M. Fog and hoar frost. P.M. Fine—nearly cloudless.
○ ♀ 27	29.889	45.4	29.738	46.0	39	41.4	40.3	33.2	42.7		ESE	{ Fine—light wind.—A.M. Lightly cloudy. P.M. Cloudless.
♂ 28	29.405	44.4	29.058	46.7	42	42.7	47.7	34.6	50.6		SSE	{ A.M. Overcast—light fog and deposition. P.M. Rain.
♀ 29	29.227	47.3	29.441	48.3	37	44.4	47.2	42.3	47.2	0.031	WSW	{ Light wind.—A.M. Fine—lightly cloudy. P.M. Lt. rain. Evening clear.
h 30	30.029	45.3	30.013	47.5	39	41.7	46.3	38.7	51.3	0.009	W	Fine—light haze.—Cloudless, A.M.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	29.949	49.1	29.906	50.8	42.3	44.6	48.0	40.4	49.1	0.808		

Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr. { 9 A.M. 29.896 3 P.M. 29.847 }

OBSERVANDA.

Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge = 83 feet 2½ in.
 ————— above the mean level of the Sea (presumed about) = 95 feet.

The external Thermometer is 2 feet higher than the Barometer Cistern.

Height of the Receiver of the Rain Gauge above the Court of Somerset House = 79 feet.

The hours of observation are of Mean Time, the day beginning at Midnight.

The Thermometers are graduated by Fahrenheit's Scale.

The Barometer is divided into inches and decimals.

METEOROLOGICAL JOURNAL FOR DECEMBER, 1833.

1833. Dec.	9 o'clock, A.M.		3 o'clock, P.M.		Dew Point at 9 A.M. in de- grees of Fahr.	External Thermometer.				Rain, in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	Remarks.
	Barom.	Attach. Therm.	Barom.	Attach. Therm.		Fahrenheit.		Self-registering.				
						9 A.M.	3 P.M.	Lowest.	Highest.			
○ 1	30.140	49.4	30.062	50.8	47	51.6	53.6	40.3	54.3		SW	{ A.M. Light fog and deposition. P.M. Overcast.—Evening, light rain.
☾ 2	30.122	51.3	30.085	51.8	47	48.6	48.0	46.7	54.3	0.006	WSW	{ A.M. Overcast. P.M. Fine.
♂ 3	29.971	49.7	29.942	51.7	44	46.3	50.8	41.7	52.3		WSW	{ A.M. Lightly cloudy—light wind. P.M. Overcast.
♀ 4	29.656	51.8	29.540	54.3	51	52.8	55.2	45.8	55.2		SSW	{ Cloudy—light wind.
♂ 5	29.511	53.4	29.475	55.3	48	48.5	48.2	47.4	48.5	0.019	SW	{ A.M. Lightly cloudy. P.M. Fine.—At night, rain and unsteady wind.
♀ 6	29.579	49.4	29.711	50.6	39	39.9	46.7	38.7	50.7	0.014	WSW	{ Fine.—A.M. Cloudless. P.M. Light clouds.
♂ 7	29.392	50.7	29.314	52.4	50	51.5	51.5	39.3	54.3	0.006	SSW	{ Rain, with light unsteady wind.
○ 8	30.069	46.7	30.088	48.3	37	38.8	43.7	37.2	53.3	0.011	W	{ Fine—light haze.—A.M. Cloudless. P.M. Lightly cloudy.—Rain at night.
☾ 9	29.564	50.7	29.564	51.9	50	53.9	55.6	37.9	55.6	0.008	WSW	{ Light rain.
♂ 10	29.881	49.6	29.808	50.2	41	42.3	46.2	41.4	46.2	0.006	SW	{ Fine.—A.M. Cloudless. P.M. Light clouds.
● ♀ 11	29.685	47.3	29.673	47.9	36	40.6	43.8	38.9	43.8		NNW	{ Light haze.—A.M. Cloudless. P.M. Fair—lightly overcast.
♂ 12	29.773	43.8	29.848	45.3	37	37.8	40.4	34.7	40.4	0.006	W	{ Fine—nearly cloudless—light wind.
♀ 13	30.072	42.3	30.111	43.5	35	36.3	39.8	32.9	41.9		WNW	{ Light haze.—A.M. Lightly cloudy—deposition—hoar frost. P.M. Fine—nearly cloudless.
♂ 14	30.132	44.4	30.128	46.6	41	42.9	46.5	35.5	47.3		WSW	{ A.M. Overcast—fog. P.M. Fine—light clouds.
○ 15	30.038	47.4	29.983	52.3	43	43.4	48.8	42.4	52.3		WSW	{ Overcast—light fog—deposition.
☾ 16	29.732	50.7	29.522	51.6	48	52.1	53.2	48.3	52.3		WSW	{ Overcast—light unsteady air.—A.M. Deposition. P.M. Light rain.
♂ 17	29.369	50.3	29.562	50.8	43	46.4	47.7	42.9	52.8	0.008	WSW	{ Strong unsteady wind, early A.M.—Fine—lightly cloudy.
♀ 18	29.417	51.4	29.701	52.4	50	52.8	50.0	42.5	52.7	0.008	W	{ Lightly cloudy.—Rain at night.
♂ 19	29.789	53.3	29.643	54.5	51	53.3	53.6	46.8	54.5		SSW	{ Overcast.—Evening, gale of wind with rain.
♀ 20	29.386	52.8	29.435	52.4	41	47.8	47.6	46.7	48.3	0.008	WSW	{ Fine—light clouds.—Morning and night, unsteady wind.
♂ 21	29.342	47.8	29.576	49.0	40	40.2	43.6	36.7	43.6	0.383	WNW	{ A.M. Lightly cloudy. P.M. Fine—nearly cloudless.
○ 22	29.594	46.7	29.269	48.5	41	42.4	48.3	37.3	52.4	0.008	SSE	{ Light rain.
☾ 23	29.242	49.5	29.311	49.6	45	46.4	46.8	41.7	48.5		E	{ Fog—dark and overcast—heavy continued rain.
♂ 24	29.404	50.0	29.311	51.7	49	49.3	51.0	43.8	51.7	0.944	S	{ Lightly cloudy and overcast.—Light wind and deposition, A.M.
♀ 25	29.457	50.0	29.748	49.4	44	46.7	43.4	43.8	46.7	0.083	NNW	{ A.M. Light fog.—Noon, rain. P.M. Clear—light clouds.—Evening, very clear.
○ ♀ 26	30.176	44.3	30.041	45.3	33	35.6	42.5	34.3	46.0		WSW	{ Lightly overcast—light fog.—Evening, rain.
♀ 27	29.796	46.8	29.744	48.1	43	43.8	46.8	34.6	46.8	0.133	WSW	{ A.M. Fog deposition. P.M. Fine—nearly cloudless.
♂ 28	29.952	44.8	29.988	46.4	35	37.3	42.9	35.5	51.4	0.061	WSW	{ Lightly cloudy and overcast.—Light fog and deposition, A.M.
○ 29	29.746	49.6	29.798	51.0	46	51.8	51.3	36.5	52.3	0.011	W	{ Fine—cloudy.—Light wind, A.M.
☾ 30	29.665	50.9	29.659	53.2	50	51.8	54.5	47.8	54.7		WSW	{ Rain.
♂ 31	29.641	50.7	29.474	52.2	49	50.3	49.6	43.6	53.2		SSW	{ A.M. Drizzling rain. P.M. Fine—nearly cloudless.
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Sum		
	29.722	49.0	29.710	50.3	43.7	45.9	48.1	40.8	50.3	1.723		
Monthly Mean of the Barometer, corrected for Capillarity and reduced to 32° Fahr.										{ 9 A.M. 29.661 3 P.M. 29.650 }		
OBSERVANDA.												
Height of the Cistern of the Barometer above a Fixed Mark on Waterloo Bridge = 83 feet 2½ in.												
..... above the mean level of the Sea (presumed about)..... = 95 feet.												
The External Thermometer is 2 feet higher than the Barometer Cistern.												
Height of the Receiver of the Rain Gauge above the Court of Somerset House = 79 feet.												
The hours of observation are of Mean Time, the day beginning at Midnight.												
The Thermometers are graduated by Fahrenheit's Scale.												
The Barometer is divided into inches and decimals.												

ADDRESS

DELIVERED AT

THE ANNIVERSARY MEETING

OF

THE ROYAL SOCIETY,

ON

Saturday, November 30, 1833,

BY

HIS ROYAL HIGHNESS

THE DUKE OF SUSSEX, K.G.

&c. &c. &c.

THE PRESIDENT.

LONDON:

PRINTED BY RICHARD TAYLOR, RED LION COURT, FLEET STREET.

1833.

ROYAL SOCIETY.

ADDRESS

OF

HIS ROYAL HIGHNESS THE PRESIDENT,

DELIVERED AT

The Anniversary Meeting, November 30, 1833.

GENTLEMEN,

THE third anniversary of my election to this Chair affords me again the opportunity of expressing my grateful thanks for the kindness which I have continued to receive from you. I would willingly enlarge upon a topic which is so grateful to my feelings, were I not conscious that by so doing I should merely vary the form of phrases which the natural expression of my sentiments prompted me to use when I have before had the pleasure of addressing you, whilst the sentiments themselves remain not merely unchanged, but, I trust, likewise unchangeable. If I am thus brief, therefore, Gentlemen, in the public declaration of my acknowledgements, from a fear of being tedious by their too frequent repetition, I hope that you will not upon that account consider them the less sincere, or that the long experience which I have had of your support and co-operation has made me less sensible of their value.

When I last had the honour of addressing you, it was a source of pride and happiness to me to be empowered to announce to you the gracious intentions of His Majesty to continue to the Royal Society the Annual Grant of two Gold Medals, which had been previously conferred on the Royal Society by his Royal Predecessor.

It must be well known to you, Gentlemen, that these Royal

Medals were not adjudged during the two first years that I presided over the Royal Society ; and as there exist many circumstances connected with the original grant and distribution of those Medals, as well as causes leading to their temporary discontinuance, with which the Fellows may not be generally acquainted, I trust that I may be allowed to enter into some details respecting them.

His late Majesty King George the Fourth announced, towards the close of the year 1825, through the medium of the Secretary of State for the Home Department (Sir Robert Peel), his gracious intention of founding two Gold Medals, of the value of Fifty Guineas each, to be annually awarded as honorary premiums, under the direction of the President and Council of the Royal Society, in such a manner as should, by the excitement of competition among men of science, seem best calculated to promote the objects for which the Royal Society was originally instituted. This munificent gift of the Patron of the Royal Society was of course accepted by the President and Council with every expression of gratitude for so valuable an addition to their means of promoting the interests of science ; and it was resolved that, in conformity with His Majesty's Commands, the Royal Medals should be adjudged for the most important discoveries or series of investigations completed and made known to the Royal Society in the year preceding the day of their award ; that their presentation should not be limited to British subjects ; and that His Majesty's effigy, if such should be the Sovereign's pleasure, should form the obverse of the Medals ; and that two Medals from the same die should be struck upon each foundation, one of gold and the other of silver.

Upon proceeding to the distribution of the Medals, it was found that the limitation of time which these Resolutions fixed was of such a nature as to interfere most materially with the proper observance of the object proposed to be secured by their foundation ; and the period was therefore, with His Majesty's sanction, extended to five years : in accordance with this arrangement the Medals continued to be awarded until the year 1830, inclusive, when the demise of His late Majesty took place, and in which year I had the honour of being elected to fill the Chair of the Royal Society.

Mr. Chantrey, to whom, in conjunction with Sir Thomas Lawrence, was intrusted the selection of the subject for the Medal, furnished the cast for the medallion of the head of His late Majesty, which was to form the obverse of it, while Sir Thomas undertook

to compose the design for the reverse. Unfortunately, that distinguished artist, either from over-delicacy or over-anxiety to produce a work of art worthy of the object for which it was intended, or from that spirit of procrastination which was unhappily too common with him, delayed its execution from year to year, and died without leaving behind him even a sketch of his ideas respecting it, though the character of such a design as would be at once classical and appropriate to the purpose, was the subject of frequent conversation, and even of favourite speculation with him. From these and other causes, to which it is not necessary for me now to advert, it arose, that, at the demise of His late Majesty, although the adjudication of ten Medals had been formally made and announced from the Chair of the Royal Society, not even the dies, much less the Medals, were forthcoming for the purpose of distribution to the various distinguished persons, some of them foreigners, to whom they had been awarded.

It cannot be necessary for me to impress upon you, Gentlemen, that the non-completion of an engagement so solemnly entered into with the whole republic of men of science, would have brought discredit not merely upon the Royal Society, but upon the personal honour of a Monarch of this country, whose name it is our especial duty as Fellows of the Royal Society, to hand down unsullied to posterity, as our munificent Patron and benefactor; and as no funds had been placed at the disposal of our Treasurer, nor in the hands of any other ostensible person to meet the very heavy expenses which must be incurred for cutting the dies and furnishing the Medals already awarded, I felt it to be my duty, when I succeeded to this Chair, to recommend to the Council the suspension of any further adjudgment of the Medals until I could have an opportunity of ascertaining the nature of the commands which had been issued concerning them by the late Sovereign through his official advisers or otherwise, and also of taking the pleasure of His present Majesty respecting their continuance in future, and the conditions to which they should be subject. These inquiries terminated in the most satisfactory manner. On a proper application to those who were intrusted with the ultimate arrangement of His late Majesty's affairs, prompt measures, as far as lay in their power, were adopted for the immediate fulfilment of every pledge which it was conceived had been given to the Royal Society and to the public at large in the name of George the Fourth.

The dies for the Medals upon the old foundation are now completed, and ready for distribution ; they bear upon the one side the likeness of His late Majesty, while the reverse represents the celebrated statue of Sir Isaac Newton, which is placed in the chapel of Trinity College, Cambridge, with such emblematical accompaniments as seemed best calculated to indicate the magnificent objects of the researches and discoveries of that great philosopher, whose peculiar connexion with the Royal Society forms the most glorious circumstance in its annals.

After having settled that part of the business, and apprized the King of my success, I then ventured to petition His Majesty for the continuance of that protection and munificence which the Royal Society had ever experienced from His Illustrious Predecessors. The Sovereign, with that just and enlightened zeal for the promotion of every object allied with the honour and prosperity of this country, which as a loyal subject I acknowledge with gratitude, while as an affectionate brother I recognise it with pride, acceded at once to my request, accepted the charge devolved upon him by the demise of the late King, and ordered, in consequence, that a fresh die should be cut, and that his effigy should form the obverse side of the medal. This work also is completed. All the dies have been executed by Mr. Wyon with such boldness of outline, depth, and delicacy of finish, as do him the highest credit: and I trust that the medals will be considered in every way worthy of the exalted rank and dignity of the Illustrious Personage in whose name this mark of Royal favour is intended to be conferred.

I am well aware that a diversity of opinion exists respecting the advantages which are likely to be conferred upon Science by a frequent distribution of medals. It is said that they must either confirm or contradict the judgement which has been either already pronounced, or which posterity will most certainly hereafter pronounce, upon the merits, pretensions, and influence of the discoveries or series of investigations which such medals are designed to commemorate: that in the first case they can confer no additional honour upon their author, whose rank has already been ascertained and fixed by the sentence of a higher tribunal, while, in the second, they can only tend to compromise the character of the scientific body by whose advice they are conferred. It is true that I would not claim infallibility for the united judgement of any association, or of any body of men, however eminent their scientific rank may be :

but it is the peculiar privilege of the great masters of Science, (and more particularly so when acting or speaking as a body,) to be able to anticipate, though not without the possibility of error, the decision of Posterity, and thus to offer to the ardent cultivator of Science that highest reward of his labours, as an immediate and well assured possession, which he might otherwise be allowed silently and doubtfully to hope for, but never be permitted to see realized : and though some powerful minds might be content to entrust the complete developement of their fame to the fulness of time, and might pursue their silent labours under the influence of no other motives but such as are furnished by their love of truth, the gratification derived from the discovery of the beautiful relations of abstract science, or from the contemplation of the agency of a Divine Mind in the harmonies and constitution of the physical world, yet it is our duty and business to deal with men as we find them constituted, and to stimulate their exertions by presenting to their view honourable distinctions attainable by honourable means ; to assure them that the result of their labours will neither pass unnoticed nor unrewarded ; and that there exists a tribunal to which they may appeal, or before which they can appear, whose decision is always for honour, and never for condemnation.

It is for these reasons, Gentlemen, that I feel myself justified in expressing my opinion that the power possessed by your Council of conferring honorary rewards is a most salutary power, provided it be exercised boldly, impartially and diligently ; and that it may greatly promote the taste for scientific pursuits in this country, by presenting a more immediate prospect than would otherwise exist, of a public and distinguished recognition of any valuable discovery, or of the completion of any important and laborious course of investigation.

I had occasion, Gentlemen, when I had last the honour of addressing you, to remark that there were many circumstances in the constitution of society in England, and perhaps in the form and working of our Government, which were unfavourable to the cultivation of Science as a distinct and, as it were, a Professional employment. Though many of the causes of this evil, if so it may be considered, are too deeply seated to be reached by any legislative enactment, and though its existence may be the result of a system, the general effects of which are favourable to the interests and happiness of society at large, yet I think it is the duty of a wise Government

to neglect no opportunity of promoting, by liberal encouragement, the development of the intellectual as well as of the physical resources of a nation. Without venturing to give an opinion from this Chair, which it would ill become me to do, whether the various Administrators of the Government of this country, for more than a century past, have adequately fulfilled this duty, by animating individuals to the cultivation of Science by all the influence at their command, I rejoice and feel proud at finding myself at full liberty to give free utterance to the language of my feelings when speaking of the Royal Patron of the Royal Society, who has shown himself in this as in every other capacity, the Friend, the Protector, and the Promoter of whatever is dignified with the name and character of Science in this country. The King, Gentlemen, is the Fountain of Honour; and although His Majesty has been graciously pleased to authorize the President and Council of the Royal Society to act as his Official Advisers, in awarding his Royal Medals, he will not on that account regard them as less worthy of being considered as the immediate gifts of his Royal bounty, and as the honourable symbols of his Royal approbation.

It will be my first duty, Gentlemen, to distribute the Ten Royal Medals which have been already adjudged during the life-time of His late Majesty, to Philosophers who are amongst the most illustrious in this country or in Europe: they form a glorious commencement of a philosophical chivalry, under whose banners the greatest amongst us might feel proud to be enrolled; and though it may appear presumptuous in me to hope that a constant succession of associates can be found, either at home or abroad, who shall be considered worthy of being ranked with those noble Founders of this Order, yet I am confident that the Council of the Royal Society will feel an honourable pride in maintaining the character of the Body whose Members are to be constituted by their choice.

In proceeding now, therefore, to call your attention, Gentlemen, to the series of great men to whom those Medals have been awarded, I shall not presume to state in detail the specific grounds upon which the decisions of your Council were founded, but confine myself to little more than their enumeration in the order of time, feeling that it would be unbecoming in me to attempt to assign them those stations which they either have taken, or are destined hereafter to take, in the temple of fame.

The first name upon the list is that of Dr. JOHN DALTON, a venera-

ble Philosopher, whose developement of the Atomic Theory and other important labours and discoveries in physical science have, at the eleventh hour, (I blush to own that it was not earlier,) first abroad, and secondly at home, secured him that public recognition of his scientific rank to which he has long been entitled. With him, Gentlemen, *posterity* may be said to have already commenced, and though full of years and honour, I rejoice to hear that he still retains the same zeal and vigour in the pursuits of science which have carried him forwards from his earliest youth in his career of discovery, in spite of all the discouragements of confined means and of the most laborious and depressing employments. It gives me great pleasure to learn that His Majesty has lately expressed his Royal approbation of his services to science by the grant of a pension, if not commensurate with his services, at least as considerable as the severity of existing regulations will allow; though I cannot refrain from expressing on this occasion my regret at the very narrow limits within which the munificence of the King and the generosity of the Nation should be confined.

The second Medal for the same year was awarded to MR. IVORY, the first of our mathematicians who transplanted to this country the profound analytical science which LaGrange, Laplace, LeGendre, Gauss and others upon the continent, had applied to the most important and sublime physical inquiries. The dignity of such investigations has not suffered by the association of Mr. Ivory's name with them, and the Transactions of the Royal Society present frequent and honourable records of his valuable labours. It is, however, a gratifying circumstance to find that Mr. Ivory is no longer a solitary cultivator of these sublime sciences; but that an English School, of which he may be considered as the Father, is now rising, and must continue to rise, whilst it boasts of such masters as our Herschels and Airys, our Lubbocks and Hamiltons, and looks forward to such disciples as they are likely to form.

The Medal which was awarded to SIR HUMPHRY DAVY was a tribute of respect to that great Philosopher towards the conclusion of his labours. He had already retired from the Chair of the Royal Society, under the admonition of those infirmities which were destined too speedily to terminate his valuable life; and the Council availed themselves of the first opportunity of marking their sense of the honour which he had conferred upon his country by his brilliant electro-chemical and other discoveries, by awarding to him, as a Fellow,

that Medal which, from natural feelings of delicacy, they could not have offered to their President.

In the following year a similar tribute of gratitude and respect was paid to Dr. WOLLASTON, who had so long honoured the Royal Society by his services and his scientific contributions, and who, towards the close of his life, had augmented its means of usefulness by his liberality.

The fame of these two illustrious men is established upon too firm a basis to require or receive additional strength or permanence from any honours which we can pay to their memories; but there are some who were connected with them by the tenderest ties of kindred and affection, who are in part the depositories and inheritors of their honours: these may cherish the possession of such monuments, as recording the reverence and respect of their contemporaries and fellow-labourers. To their hands, therefore, we commit them, as our last public offering to their memories. *Illi habeant secum, serventque sepulchro.*

The two other Medals for the corresponding years were awarded to two distinguished foreign Astronomers. The first, to PROFESSOR STRUVE, of Dorpat, who is so justly celebrated for his numerous and valuable observations of double stars,—a department of astronomy which is daily acquiring an increase of interest and importance, from the new and extensive views which it is beginning to open to us of the constitution of the remoter parts of the universe, and of the laws which seem to govern some at least of the periodical changes which they are undergoing. The second, to PROFESSOR ENCKE, of Berlin, the greatest of modern astronomical calculators, who first determined and predicted the motion of the comet which is justly signalized by his name, with an accuracy approaching to that which before belonged to the ephemerides of the planets only; and who still more has subjected the discrepancies between its tabulated and observed places to so accurate an analysis as to make them the foundation of the most novel and unexpected speculations respecting the existence of a resisting medium, which is capable of sensibly affecting the motions of those extraordinary bodies which obey the laws of gravity, at the same time that they seem to present few or none of those characters with which our notions of matter and substance are commonly associated.

The Medals for the years 1829 and 1830 were adjudged to SIR CHARLES BELL, to PROFESSOR MITSCHERLICH of Berlin, to SIR DAVID BREWSTER, and to M. BALARD of Montpellier.

To the first, for his elaborate experiments and discoveries relating to the nervous system, which place him in the highest rank of the physiologists and anatomists, not merely of this country, but of Europe.

To the second, for his theory of isomorphism, one of those great generalizations in the sciences of chemistry and crystallography which are reserved for men of large and extensive views, and which may be considered as constituting a great epoch in their history.

To the third, for his discoveries relating to the polarization of light, the most important laws of which he determined; forming one of those great series of experimental investigations relating to the properties of light and the optical properties of crystals which are unrivalled, since the time of Newton, for their variety, their delicacy, and perhaps also for their theoretical importance.

To the last, for a singularly successful and well developed example of chemical analysis, which terminated in the discovery of a new, and hitherto undecomposed body, Bromine.

I now come to the consideration of the Medals upon the Foundation of His present Majesty; and it is the King's pleasure that the President and Council of the Royal Society should be considered as his official advisers, in the award of an honour which emanates immediately from himself. His Majesty has also been graciously pleased to prescribe the general Rules and Principles which shall regulate their distribution hereafter. The King has therefore commanded that they shall be adjudged annually, and that the award shall be announced on the day of the Anniversary Meeting of the Royal Society; that the Memoirs which shall be entitled to receive them, whether composed by Foreigners or by Englishmen, shall be communicated to the Royal Society; and that the *general* subject matter of such Memoirs shall be prescribed and announced by the Council at least three years preceding the day of their award: and also, that for the present and the two following years, the principle of their distribution shall be the same as that which has hitherto been adopted, with the additional condition, that the succession of branches of science which shall be selected as entitled to these rewards, shall be the same as that which shall be hereafter followed when the cycle of their regular distribution begins.

The selection of the subjects which should compose this cycle was left to the Council of the Royal Society, who have made such a choice as seemed to them best calculated to comprehend every de-

partment of science and to prevent the jealousies which might arise from the recurrence of similar subjects in immediate or too close succession: the subjects themselves and their periodical order (determined by lot) are as follow:—

1. Astronomy.
2. Physiology, including the Natural History of Organized Beings.
3. Geology and Mineralogy.
4. Physics.
5. Mathematics.
6. Chemistry.

In conformity with these Regulations, which form the existing law for the distribution of the Royal Medals, they have been awarded for the current year to PROFESSOR DE CANDOLLE, of Geneva, for his numerous and valuable researches and investigations in Vegetable Physiology, as detailed in his Work, entitled "*Physiologie Végétale*," published in the year 1832; and to SIR JOHN FREDERICK WILLIAM HERSCHEL, for his Paper "*On the Investigation of the Orbits of Revolving Double Stars*," inserted in the Fifth Volume of the Memoirs of the Royal Astronomical Society.

The science of Vegetable Physiology has at all times presented extraordinary difficulties, and although it has employed the talents and the industry of a great number of philosophers, from the earliest period, little progress has been made in obtaining an exact knowledge of the minute organization of plants, and of the mode in which their functions are exercised, at least, when compared with the great advance which has taken place in the analogous sciences which relate to the comparative anatomy and physiology of animals.

The structure of vegetables, in consequence of its minuteness and intricacy, is involved in the greatest obscurity; its investigation requires the application of powerful microscopes, and is liable to all the fallacies peculiarly incident to such observations: and the greater part of vegetable physiology being dependent on the full and accurate knowledge of that organization, is exposed to the same causes of uncertainty. But the progress of this department of science has suffered less from the want of accurate and sufficiently multiplied observations, than from the absence of a well-compacted and consistent theory to connect them together; and it was chiefly with a view to supply this great deficiency that the admirable work of Professor de Candolle was written, which has been selected by the Council as justly entitled to one of the Royal Medals. There is, in fact, no

branch of botanical science which has not been greatly benefited by his valuable labours : his *Théorie Élémentaire de la Botanique* and his *Organographie Végétale* have made most important additions to our knowledge of descriptive botany, whilst in his *Physiologie Végétale*, by a most careful analysis and examination of the influence both of external and internal physical agents upon the organs of plants in the great functions of their nutrition and reproduction, by tracing them throughout the whole course of their operations, and by connecting their results with the well-known and well-established deductions of chemistry and other sciences, he has shown that he is also entitled to claim the rank and distinction of an inductive philosopher of a very high order.

The mention of the name of the second of these distinguished Philosophers to whom the Royal Medals for the present year have been adjudged, recalls my attention to the circumstances under which he has recently quitted his home and his country to pursue his labours in another hemisphere. He has devoted himself, as you well know, for many years at least, as much from filial piety as from inclination, to the examination of those remote regions of the universe into which his illustrious father first penetrated, and which he has transmitted to his son as an hereditary possession, with which the name of Herschel must be associated for all ages. He has subjected the whole sphere of the Heavens within his observation to a repeated and systematic scrutiny. He has determined the position, and described the character of the most remarkable of the nebulae. He has observed and registered many thousand distances and angles of position of double stars ; and has shown, from the comparison of his own with other observations, that many of them form systems whose variations of position are subject to invariable laws. He has succeeded, by a happy combination of graphical construction with numerical calculations, in determining the relative elements of the orbits which some of them describe round each other, and in forming tables of their motions ; and he has thus demonstrated that the laws of gravitation, which are exhibited as it were in miniature in our own planetary system, prevail also in the most distant regions of space : a memorable conclusion, justly entitled, by the generality of its character, to be considered as forming an epoch in the history of astronomy, and presenting one of the most magnificent examples of the simplicity and universality of those fundamental laws of nature by which their Great Author has shown that He is the same to-day and for ever, here and everywhere.

A discovery like this, which we are this day called upon to commemorate, forms a noble, but I trust only temporary termination to Sir John Herschel's European labours. He has long contemplated a voyage to the Cape of Good Hope, as a favourable station for observing the constellations of the Southern Hemisphere, and the magnificent nebulae which it contains; and when we consider the space-penetrating power of his instruments, such as has never yet been brought to bear upon them; his skill and long experience and systematic diligence as an observer; his perfect familiarity with the class of phenomena which are to be observed; his sagacity in interpreting and disentangling the most complicated appearances; and his profound knowledge of physical as well as practical astronomy, we may look forward to a harvest of discoveries, such as will not only extend the existing boundaries of science, but add to the lustre of a name which is known and revered in every region to which European civilization has reached.

It has been said that distance of place confers the same privileges as distance of time, and I should gladly avail myself of the privilege which is thus afforded me by Sir John Herschel's separation from his country and friends, to express my admiration of his character, in stronger terms than I should otherwise venture to use; for the language of panegyric, however sincerely it may flow from the heart, might be mistaken for that of flattery, if it could not thus claim somewhat of an historical character: but his great attainments in almost every department of human knowledge, his fine powers as a philosophical writer, his great services and his distinguished devotion to science, the high principles which have regulated his conduct in every relation of life, and, above all, his engaging modesty, which is the crown of all his other virtues, presenting such a model of an accomplished philosopher, as can rarely be found beyond the regions of fiction, demand abler pens than mine to describe them in adequate terms, however much inclined I might feel to undertake the task. That he may live to accomplish all the objects which have induced him to transport himself to another continent, and that he may long survive his return to witness the respect, reverence and gratitude of his countrymen, is my earnest prayer, in which I am quite sure that you, Gentlemen, will cordially join.

It now becomes my painful duty to call your attention to the names of those Fellows and Foreign Members whom the Royal Society has lost during the last year.

SIR JOHN MALCOLM was born in the year 1769, a year remarkably fertile in the production of great men*. He was one of a family of seventeen children, which enjoyed the singular distinction of having three of its members created Knights of the Bath in the same year. At the early age of thirteen he was sent to India as a Cadet, and learnt his first lessons of military service in the celebrated wars of the Mysore; and during an almost uninterrupted residence of nearly forty years, he was employed both in civil and military duties, frequently of great importance and difficulty, in almost every part of Central India; and it was chiefly owing to the opportunities afforded by this long intercourse with the natives of all classes and nations, aided by the system of carefully recording his observations of their manners and customs, and by his perfect knowledge of their languages, that he was enabled to acquire the most intimate acquaintance with their habits, their feelings and their prejudices, at the same time that he secured, in a very uncommon degree, their confidence and respect by his strict impartiality, and by his considerate attention to their wants and their interests.

He was twice sent as Ambassador to Persia, where he conducted negotiations of great delicacy and difficulty in such a manner as to maintain the honour, at the same time that he secured the interests of the Government which he represented: he was, in fact, eminently qualified for the discharge of such a duty by his profound knowledge of the Persian language and literature, and by the conformity of his own manners with those of that lively and polished nation. Nor were the fruits of his mission political merely, inasmuch as they led to the production of his *History of Persia*, a work of great research and of standard value; to his *Persian Sketches*, so remarkable for their wit and vivacity, and, I believe, likewise for the truth of the pictures of manners which they furnish; and also to a volume of Poems, which display no inconsiderable powers of versification.

Sir John Malcolm was a voluminous writer, and amongst other works may be particularly mentioned his *Political History of the Government of India, from the year 1784 to the Present Time*; his very interesting *Sketch of the Sikhs*, and his *History of Central India*. In all his writings he has shown himself to be the friend of the native population, and the zealous advocate of a system of government such as would reconcile the interests of the governed with

* Napoleon, Wellington, Cuvier, &c.

those of the governors: and though he has very clearly demonstrated that our Indian Empire must be progressive in order to be permanent, and that external attacks upon it must not only be repelled, but the means of renewing them either greatly weakened or altogether removed, yet he stigmatizes with just reprobation the commencement or continuance of wars of conquest merely, which are not rendered necessary by previous and adequate provocation. Upon all such subjects Sir John Malcolm was eminently entitled to pronounce an authoritative opinion, from his great experience, both military and civil, and from his almost unequalled knowledge of the political interests and relations of all the various nations who compose or border upon our Indian Empire.

Sir John Malcolm returned to England in 1822: in 1827 he was appointed Governor of Bombay and Central India. He retained this important situation for three years, when he was recalled for the purpose of taking part in the discussions which were likely to arise upon the renewal of the East India Company's Charter. He was shortly after his return elected Member of Parliament for Launceston; but the questions which almost entirely absorbed the attention of Parliament and of the public at that period were not calculated for the favourable display of his peculiar powers. His last public address was made at a meeting in London in honour of his illustrious countryman Sir Walter Scott, of whose genius and writings he was an enthusiastic admirer: on the following day he was attacked by paralysis, from which he never recovered; and he died at his house in London on the 31st day of May last.

Sir John Malcolm was tall and commanding in his person; his manners were remarkably free and unconstrained, and his conversation rapid and animated; and notwithstanding his long and intimate intercourse and association with Oriental people and Oriental languages and with scenes of life altogether different from those in which his earlier boyhood had been passed, yet he continued to speak with the accent of his countrymen, and to remember their national traditions with all the vividness and to recite their national poetry with all the enthusiasm, which characterize our earliest and deepest impressions. As a father, a husband and a brother he was eminently kind and affectionate; and few persons have been more generally beloved by their friends for their social virtues, or more respected and revered for their great talents and attainments and for their eminent public services.

I observe with pleasure that a monument, from the chisel of Mr. Chantrey, is to be erected to his memory in Westminster Abbey, for which ample funds have been provided by the almost spontaneous contributions of his friends; and it is worthy of remark that amongst the subscribers is to be found the name of an Eastern Potentate, the Pacha of Egypt, the founder of a great empire, and still more distinguished for his triumphs over Eastern prejudices, who became acquainted with Sir John Malcolm upon his return from Bombay, and who has most gladly availed himself of this opportunity of expressing his respect for the memory of his friend.

MR. WILLIAM MORGAN was the author of several papers in our Transactions, chiefly upon the subject of the value of reversions contingent upon different cases of survivorship. For two of these papers, printed in 1788 and 1789, he received the Copley Medal. He was one of the first authors who rejected altogether the hypothesis of the equal decrements of life which had been introduced by De Moivre, partly from the want of correct tables, and partly for the purpose of simplifying the formulæ employed in the calculation of contingent reversions; and he showed in what manner such questions could be practically solved with reference to the real probabilities of life. Mr. Morgan was the nephew of the celebrated Dr. Price, whose memoirs he has written, and some of whose works he has edited; and he partook largely, at one period at least, of some of the political and financial opinions of that ardent character, particularly relating to the dangers of a national bankruptcy from the rapid increase of our National Debt. He was appointed early in life, chiefly by his uncle's influence and recommendation, to the situation of Actuary of the Equitable Assurance Company, which he continued to hold for nearly sixty years; and the unexampled wealth and prosperity of that great establishment may be in a great degree attributed to the confidence inspired by the correct principles of calculation and of management which he introduced: and though he was exposed towards the close of life to many attacks and much opposition, in consequence of his too rigid adherence to a system which might be calculated to do injustice to some classes of insurers, yet no small indulgence is due even to the prejudices of a man who had done so much service to society, by establishing upon a firm basis the security of establishments which act as safeguards against the fluctuations and vicissitudes of life, and which thus encourage

habits of providence and of foresight amongst the higher and middle classes of the community.

MR. THOMAS ALLAN, an eminent citizen of Edinburgh, was the author of a work on Mineralogical Nomenclature, and of several papers on geology and mineralogy in the Transactions of the Royal Society of Edinburgh, and elsewhere. He was greatly distinguished for his accurate knowledge of mineral species and their varieties, and of all the delicate and minute distinctions of external characters by which they are separated from each other; and his collection of minerals has been justly celebrated for its great extent and perfect arrangement. In the year 1812 he joined Sir George Steuart Mackenzie in an Excursion to the Faroe Islands, where he greatly enriched his collection, particularly in zeolites. This expedition was undertaken for the purpose of ascertaining whether, in a Trap Country, where no traces of *external* volcanoes existed, any thing similar to the peculiar features of the rocks of Iceland was to be found: and his Account of the Mineralogy of these Islands, in which his object has been to describe, without relation to theory, whatever appeared to him interesting in a geological point of view, was read before the Royal Society of Edinburgh in the beginning of the following year, and printed in the seventh volume of their Transactions. He adopted in early life the opinions of Dr. Hutton, though his papers on some points in geology in the neighbourhood of Edinburgh, and in the environs of Nice, show him to have been an accurate and an unprejudiced observer. He was a person of active habits and character, a liberal supporter of public charities and useful institutions, and an ardent and even enthusiastic friend of all the schemes for the improvement and decoration of his own magnificent and picturesque metropolis.

DR. WILLIAM BABINGTON was a distinguished physician in the City of London. He was formerly a lecturer on materia medica and on chemistry at Guy's Hospital, and he was the author of a Systematic Arrangement of Minerals, founded upon a joint consideration of their chemical, physical and external characters; and also of other works, of less importance, upon mineralogical arrangement. He was the active and disinterested friend of science and of men of science, from the time of Priestley to that of Sir Humphry Davy; and though the absorbing duties of a laborious profession prevented his taking a leading part in original inquiries, he was well acquainted with the

existing state of knowledge, particularly in geology, physiology and chemistry. He was one of the first founders of the Geological Society; and the earliest meetings of that distinguished body, which has contributed so powerfully to the advancement of geological knowledge, were held at his house. He was a person of great simplicity of manners, a warm and active friend, zealous in the promotion of objects of charity and usefulness, and in the practice of his profession singularly kind to the poor.

The death of LORD DOVER in the course of this year excited an unusual degree of public sympathy and sorrow, from his youth and high birth, his domestic virtues, and perhaps also his domestic happiness, his unsullied public character, his cultivated taste for the arts, and his liberal and enlightened patronage of artists, and most of all from the promise of the highest literary distinction afforded by his very interesting historical memoirs and other literary productions. Such qualities and attainments, whilst they give dignity to all who possess them, acquire a peculiar grace and lustre when found in those classes of society in which the possession of rank and wealth separate altogether the pursuit of knowledge and of fame from all taint of a suspected union with the desire of mere personal aggrandizement.

THE REV. BEWICK BRIDGE, Fellow of St. Peter's College, Cambridge, obtained the highest mathematical honours in his own academical year. He was for many years Mathematical Professor in the East India College at Haileybury, and was the author of several elementary works on different parts of mathematics, which are remarkable for their judicious adaptation to the capacities of ordinary students, by the union of simplicity and fulness in the developement of first principles,—a species of merit which those only can duly estimate whose experience in education has shown it to be very rarely attained. Mr. Bridge was a person of great benevolence, who devoted his life and fortune to the promotion of objects of charity and public utility, and whose purity of character and kindness of heart secured him the affectionate attachment of a large circle of friends.

CAPTAIN LYON became first known to the public from his having accompanied the late Mr. Ritchie in his journey into the interior of Africa. His companion died at Moorzouk, and after encountering the ordinary succession of sufferings and dangers which characterize the melancholy records of African discovery, he succeeded in effecting his return, and published a very modest and interesting journal

of his travels. He afterwards accompanied Captain Parry in the second voyage to the Arctic Regions, as commander of one of the two ships which composed that expedition. After his return he was chosen, from a knowledge of his enterprising and energetic character, to conduct a party of English miners to Zacatecas and Bolaños in Mexico, and to undertake the management of the first of these mining establishments: and though he continued there for a short time only, being compelled by domestic circumstances to return to England, his services were of such a kind as to produce the most important results. His Mexican adventures form a narrative full of interesting, amusing and instructive details. He was afterwards chosen by the Brazilian Company to superintend the celebrated gold mines at Gongo Soco, in the province of Minas Geraes, which under his management became so productive, as fully to vindicate and redeem the character of South American mining speculations. Upon quitting their service he engaged in mining adventures of his own; and it was in returning to England, in consequence of an accidental injury which he received in the course of his operations, that he died at sea, in the thirty-seventh year of his age.

MR. JOSHUA BROOKES was for more than forty years a distinguished teacher of anatomy, and it is said that during the course of his life he had superintended the anatomical education of more than seven thousand pupils. He had formed a Museum of human and comparative anatomy, which was second only in extent and value to the Hunterian Collection, and to which he gave the most ready and liberal access both to his pupils and to the public. To the completion of this museum, and to the instruction of his pupils, he devoted the whole of his time and of his income; and it was a melancholy circumstance that he should have been compelled towards the close of his life, when his health, and with it his sources of income were declining, from the pressure of pecuniary difficulties, to consent to the sale of his museum. The dispersion of this collection was to him a source of the most poignant distress; and the latter years of a long life which had been devoted with singular disinterestedness to the public service, were embittered at once by the pressure of poverty and the despondency occasioned by the annihilation of those hopes of having raised a lasting monument to his fame, which had formed the great object of his ambition.

LIEUTENANT-COLONEL JOHN BAILLIE went to India as a Cadet in 1791, and from the commencement of his residence he devoted himself

with great diligence to the study of the Oriental languages. Upon the establishment of the College of Fort William, in 1800, he was appointed Professor of the Arabic and Persian languages, and of the Muhammedan law, a situation which he continued to fill with great credit and distinction for several years. He was the author of *Tables elucidatory of a Course of Lectures on Arabic Grammar*, of *A Collection of the original Texts of the five most celebrated Grammars of the Arabic Language*, and of *A Translation from the Arabic of a Digest of the Muhammedan Law*, of which one volume only out of four was published. His Oriental studies appear to have terminated upon his appointment as Resident at Lucnow, where he continued for several years. He quitted India in 1818, and in 1823 he was appointed a Director of the East India Company. Colonel Baillie was one of the founders and most active supporters of the Royal Asiatic Society; and he represented his native town, Inverness, and its contributory burghs, in two successive Parliaments. His collection of Persian, Arabic, and other Oriental Manuscripts is said to have been one of the most extensive and valuable that was ever brought to this country.

MR. JOSEPH WHIDBRY was for nearly fifty years a Master in the Navy, and had been one of the companions of Vancouver in his voyage round the world. He was a person of great practical knowledge and skill, and possessed of more than ordinary general attainments; and he was in consequence selected by the Government to superintend, under the direction of the late Mr. Rennie, the execution of that great national work, the Breakwater at Plymouth. He was the author of three papers in our Transactions: one on the means adopted for raising the Dutch frigate *Ambuscade*, which had been sunk at the Nore; and the other two on certain fossil bones discovered in the limestone quarries at Oreston, near Plymouth.

ADRIEN MARIE LE GENDRE, one of our Foreign Members, and one of the most illustrious analysts in Europe, was born in Paris in 1752, and died on the 10th of January last, in the eighty-first year of his age. After the completion of his studies at the Collège Mazarin, he devoted himself to mathematical and scientific pursuits, which he continued, with singular perseverance and industry, for the remainder of his life. At the age of thirty he gained the two prizes proposed by the Academies of Berlin and Paris; the one for a memoir on the motion of projectiles in a resisting medium, and the other for a memoir on the attraction of spheroids upon any external point what-

ever. It was this second memoir which gained him, in the following year, a place in the Academy, as the successor of D'Alembert, and which attracted in a peculiar degree the attention of mathematicians. The problem which it treated was one of the greatest importance and difficulty, particular cases only of which had been successfully treated by Newton, MacLaurin and Clairaut, but which he attacked in all its generality, and mastered its difficulties "sword in hand," to use the expressive language of Lagrange, when speaking of this admirable memoir. An important proposition discovered by Laplace led to a second, and a happy substitution, proposed and applied by Mr. Ivory, to a third resumption of this problem, which has finally terminated in such an organized system of approaching its difficulties, that it has lately been reduced to the order of those propositions which are included in the higher class of elementary books*.

It was in the course of his researches upon the attraction of spheroids that his attention was first drawn to the subject of elliptic integrals, concerning which his first memoir was published in 1786. He continued to pursue this most interesting and difficult branch of analysis in a succession of works, for a period of nearly forty years, and had finally collected his entire labours upon it in two volumes quarto, which he published in 1827, forming a vast treasure of analytical knowledge. He had hitherto laboured in this field without a colleague and without a rival, when two young analysts of singular genius and boldness, M. Abel, of Christiania in Norway, and M. Jacobi, of Königsberg, announced, almost simultaneously, the discovery of propositions which have led to an immense extension of this theory. LeGendre, with a nobleness of character which can only result from the most disinterested love of truth, was the first to welcome the appearance of these illustrious strangers upon his own territories, to make known the full importance of their discoveries, and to develop all their consequences; and although already arrived at an extreme old age, he commenced and finished, with all the vigour and activity of youth, a third volume, expressly devoted to the discussion and classification of these *ultra-elliptic* functions, and to point out their analogy with, and relation to other classes of transcendents which he had himself already considered, or to which they would naturally lead.

* Poisson, (*Traité de Mécanique*, second edition,) who has obtained an expression for the attraction under a finite form.

M. LeGendre was the author of a justly celebrated treatise or essay on the Theory of Numbers, which first reduced the numerous and disconnected discoveries of Fermat, Euler and Lagrange to systematic order. He was the proper author, amongst many other discoveries, of the *law of reciprocity* between any two prime numbers, one of the most fertile and important in this theory, though its complete establishment was reserved for Gauss, whose work on this subject has gained him so just a reputation. Notwithstanding, however, the labours of these great men, this most important department of analysis still continues to be too much insulated, both in its form and its treatment, from the other branches of algebra, though much has been done to reunite them by the very valuable and original researches of that distinguished analyst M. Libri, of Florence, who has been recently naturalized in France, and who has succeeded M. LeGendre in his place in the Institute.

The work of M. LeGendre, on Geometry, has enjoyed a singular reputation, and has been most extensively used, particularly on the continent of Europe, in the business of education. It may be doubted, however, whether this work has altogether merited the high character which it has obtained: it has rather increased than cleared away the difficulties of the theory of parallels, which have so long embarrassed the admirers of ancient geometry and of the Elements of Euclid; and it has not succeeded, at least in any essential degree, in adding to the simplicity of the demonstrations, or to the clear and logical connexion and succession of the propositions of that unrivalled and unique elementary work, which has alone maintained its place amongst all civilized nations for more than two thousand years. It is proper, however, to observe that the notes appended to this work are full of valuable and original remarks, and are justly celebrated for the elegance of the demonstrations which they furnish of many important propositions.

M. LeGendre was the author of many other works and memoirs, containing many valuable series of investigations, and very important discoveries. He first attacked the great problem of the determination of the orbits of comets by general methods, which display all the resources of his analysis; though astronomers have not found it expedient to make use of his methods in the actual calculation of their elements, which is the only proper test of their practical value, though it may not be decisive of their theoretical perfection. He was the author of the method of *the least squares of the errors*, for the pur-

pose of determining the most probable mean amongst the results of a great number of observations, of which such extensive use is now made in practical astronomy: a celebrated and most useful theorem in geodesy goes by his name; and there are few departments of analysis or of dynamics which have not been benefited by his labours.

M. LeGendre was associated with Méchain and Cassini in the operations which were instituted in 1787, and finished in 1790, for the junction of the meridians of Paris and London. He was one of the three Members of the Council nominated for the purpose of introducing the new metrical system into France in 1795, and he constructed the formulæ employed for the calculation of the tables for the centesimal division of the quadrant. He was nominated, both during the Imperial and subsequent Government, to various public employments, chiefly, however, of an honorary nature, requiring no great sacrifice of time or attention,—a fortunate circumstance, when it is considered to what important labours the leisure of his long life appears to have been devoted.

The next name which I feel called upon to notice is that of FRANCISCO DE BORJA GARÇÃO STOCKLER, BARON DA VILHA DA PRAIA, a Lieutenant-General in the Portuguese army, and formerly Secretary of the Academy of Sciences of Lisbon: he was the author of several Papers in the Transactions of the Lisbon Academy, chiefly on subjects connected with the developement of functions, and also of a volume of Poems. In 1795 he published his *Methodo dos Limites*, and in 1824 his *Methodo inverso dos Limites*. In this latter work, written late in life, he adopted the opinions of the well-known Hoene de Wronski, which led to its rejection by the Academy of Lisbon, upon the report of two Academicians, when it was offered to them for publication. His works are not of a kind to exercise much influence upon the progress of science, and some of them are examples of the danger of dealing with formulæ of such great generality that their proper import and derivation are not very clearly understood by those who use them.

Of the five Foreign Members whose names appear in the lists of the additions which the Royal Society has received during the last year, it is with deep regret that I observe those of two of them also in the record of its losses: the first is that of Professor Meckel of Halle, the second that of M. Desfontaines of Paris.

DR. JOHN FREDERICK MECKEL, Professor of Anatomy in the University of Halle, was the third member of a family singularly illustrious in the annals of physiological and anatomical science. His grand-

father, at the beginning of the last century, was probably the greatest anatomist of his age, and was the founder of that collection which has become, by the additions of his son and of his grandson, the richest and the best arranged in Germany. His father was likewise an eminent anatomist, and greatly distinguished for his success in the practice of physic and of surgery, and for his general attainments. It was for the purpose of enriching the great collection which he inherited, and of completing those departments of it in which it was deficient, that young Meckel first directed his whole attention to comparative anatomy; but the results of his labours were not confined to his museum: he published a German translation of the *Anatomie Comparée* of Cuvier, which was enriched with many valuable notes. This was followed by his *Contributions to Comparative Anatomy*; by his *System der vergleichenden Anatomie*, which he did not live to complete; his *Tabulae Anatomico-pathologicae*; his *Handbuch der pathologischen Anatomie*; his work *On Human Monsters*, and several memoirs relating to this branch of medical science, which display a remarkable union of laborious research with the most profound and original views relating to the phenomena of animal life. He devoted a great portion of his time to the publication of the *Archiv für Anatomie und Physiologie*, one of the most valuable and instructive periodical publications on medical and physiological science which appeared in Germany. One of his last works, on the *Lymphatic System*, which is upon a magnificent scale, was dedicated to the celebrated Sömmerring, upon the completion of his fiftieth year from the period of his inauguration as Doctor in Medicine, as a tribute of respect to one who had been his own preceptor, the fellow-student of his father, the follower and pupil of his grandfather, the intimate friend of his family for three generations, and who was also one of the few of his living rivals in the sciences which he cultivated.

Meckel was only fifty years old at the time of his death: he united in a very remarkable degree the power of correct and philosophical generalization with the most profound and accurate knowledge of anatomical details; and though he may have left in his own country some who may equal or even surpass him in particular departments of human and comparative anatomy or physiology, there is no one of his countrymen, if, perhaps, Tiedemann be excepted, who can be considered as having made such important additions to our general views in those sciences.

RENÉ LOUISE DESFONTAINES, Professor of Botany at the Jardin du Roi, and one of the most distinguished botanists in Europe, was born at Tremblay in 1752. In the course of the years 1782 and 1783 he travelled, for the purpose of forming botanical collections, to the North of Africa, penetrating as far as the range of Mount Atlas; and his *Flora Atlantica*, which was published in 1798, a splendid and richly decorated work, contains the principal results of his labours. It was in the same year that his celebrated memoir on the Organization of Monocotyledonous Plants was read to the Institute, in which he demonstrated the different manners in which the ligneous fibres are developed in plants with simple and double cotyledons, and thus laid the foundation of two great and fundamental divisions in the vegetable kingdom*. He was the author of the *Tableaux de l'Ecole de Botanique du Muséum d'Histoire Naturelle*, of the *Histoire des Arbres et Arbrisseaux qui peuvent être cultivés en pleine terre sur le Sol de la France*, of a *Manuel de Cristallographie*, according to the system of Romé de l'Isle, of many elaborate articles in the *Dictionnaire des Sciences Naturelles*, and other similar publications; and of a great number of Memoirs, chiefly in the *Annales du Muséum d'Histoire Naturelle*, which were for the most part descriptive of new genera and species of plants cultivated in the Jardin du Roi, the management of which had devolved upon him conjointly with MM. de Jussieu and Thouin.

M. Desfontaines was a person of mild and inoffensive manners, and perfectly free from those feelings of jealousy which tend to provoke either opposition or controversy. For a considerable period before his death he laboured under the affliction of total blindness, and was thus debarred from the continuation of those pursuits which had constituted at once the delight and the business of his life: and it was a fortunate circumstance that a visitation of Providence, which under ordinary circumstances would have produced a spirit of repining and discontent, was deprived of more than half its bitterness and severity by the spirit of contentment and resignation with which it was met.

At the conclusion of my Address to you, Gentlemen, last year, I felt called upon, at once by my subject and my feelings, to pass from the notice of the *certain* losses which the Society had sustained during

* Traces of this distinction in the structure of Monocotyledonous and Dicotyledonous plants may be found in the writings of Grew, Malpighi, and Daubenton, though its full development was reserved for M. Desfontaines.

the preceding year, to one which circumstances at that time rendered too probable. The long absence of Captain Ross and his companions, the perilous enterprise upon which they were engaged, the fearful alternative of shipwreck or famine which seemed their almost inevitable fate, had left few elements for hope, except in those who steadily trust in the unlimited resources of Providence to accomplish its ends, however remote and wonderful. I rejoice at the unlooked-for accomplishment of that hope, and I know that you, Gentlemen, one and all will equally participate with me in these feelings. Captain Ross and his brave companions were "lost, and are found;" and I trust that the enthusiastic welcome which has met them upon their return will convince them that the heart of their country is that of a parent.

I forbear, Gentlemen, to mix up other topics with the expression of those feelings to which this happy event naturally gives rise, and however important may be the contributions to geography or to science which these perilous and painful adventures may have produced, I consider them, in the present condition of my feelings, but as dust in the balance, when compared with the knowledge of the important fact of the recovery of our long lost brethren.

Permit me then, Gentlemen, in your name as well as in my own, to offer to Captain Ross, whom I rejoice to see amongst us, our most cordial congratulations upon his happy return, and to express our hope that the sympathy and respect of his countrymen which he has already experienced, and which, I trust, he will retain for the remainder of his days, will form one of the best compensations for the long sufferings which he has endured, and for the incomplete success of an enterprise presenting difficulties from the certain operation of the laws of the physical world, which not merely baffle, but almost annihilate, the powers of the bravest, the strongest, and the most persevering of men.

THE END.

PRINTED BY RICHARD TAYLOR,
AND LION COURT, FLEET STREET.

T H E R O Y A L S O C I E T Y .

30th NOVEMBER, 1833.

THE ROYAL SOCIETY. 1833—4.

HIS SACRED MAJESTY KING WILLIAM IV., PATRON.

HIS ROYAL HIGHNESS ERNEST AUGUSTUS, DUKE OF CUMBERLAND.
HIS ROYAL HIGHNESS AUGUSTUS FREDERICK, DUKE OF SUSSEX.
HIS ROYAL HIGHNESS WILLIAM FREDERICK, DUKE OF GLOUCESTER.

HIS IMPERIAL MAJESTY THE EMPEROR OF ALL THE RUSSIAS.
HIS MAJESTY THE KING OF THE BELGIANS.
HIS ROYAL HIGHNESS JOSEPH FRANCIS OSCAR, CROWN PRINCE OF
SWEDEN AND NORWAY.
HIS ROYAL HIGHNESS CHRISTIAN FREDERICK, HEREDITARY PRINCE
OF DENMARK.
HIS IMPERIAL HIGHNESS THE ARCHDUKE JOHN OF AUSTRIA.
HIS IMPERIAL HIGHNESS THE ARCHDUKE LOUIS OF AUSTRIA.
HIS IMPERIAL HIGHNESS THE ARCHDUKE MAXIMILIAN OF AUSTRIA.

THE COUNCIL.

HIS ROYAL HIGHNESS THE DUKE OF SUSSEX, K.G.—PRESIDENT.

FRANCIS BAILY, Esq.
PETER BARLOW, Esq.
WILLIAM THOMAS BRANDE, Esq.
BENJAMIN COLLINS BRODIE, Esq.
MARK ISAMBARD BRUNEL, Esq.
JOHN GEORGE CHILDREN, Esq.—SEC.
WILLIAM CLIFT, Esq.
REV. JAMES CUMMING.
MICHAEL FARADAY, Esq.
DAVIES GILBERT, Esq.

GEORGE BELLAS GREENOUGH, Esq.
REV. PHILIP JENNINGS, D.D.
CHARLES KONIG, Esq.—FOREIGN SEC.
JOHN WILLIAM LUBBOCK, Esq.—TREAS.
REV. GEORGE PEACOCK.
WILLIAM HASLEDINE PEPYS, Esq.
REV. BADEN POWELL.
PETER MARK ROGET, M.D.—SEC.
REV. ADAM SEDGWICK.
CAPT. WILLIAM HENRY SMYTH, R.N.

FELLOWS OF THE SOCIETY.

- George, Earl of Aberdeen, K.T. *Trust. Brit. Mus.*—President of the Society of Antiquaries. Argyll-house.
- Hon. George Charles Agar, M.A. *F.L.S.* Connaught Terrace.
- Archibald, Marquess of Ailsa, K.T. Whitehall-gardens; and Culzean-castle, Ayrshire.
- Rev. Archibald Alison, LL.B. *F.R.S.E.* Edinburgh.
- William Allen, Esq. *F.L.S. F.G.S. F.R.A.S.* Plough-court, Lombard-street; and Paradise-row, Stoke Newington.
- Thomas Amyot, Esq. *Treas. S.A.* 13 James-street, Westminster.
- John Proctor Anderdon, Esq.
- James Andrew, LL.D.
- Charles George, Lord Arden. *F.S.A.* 26 St. James's-place.
- James Henry Arnold, Esq. LL.D. *F.S.A. F.G.S.* 17 Lincoln's-inn-fields.
- John James Audubon, Esq. *F.R.S.E.* North America.
- Charles Babbage, Esq. M.A., Lucasian Professor of Mathematics, Cambridge. *F.R.S.E. M.R.I.A. F.R.A.S. M.C.P.S. Acad. Reg. Sc. Masil., Hafn., et Divion., ex intim.: Acad. Amer. Art. et Sc. Bost., Socc. Reg. Œcon. Boruss., et Phys. et Hist. Nat. Genev., Socius. —Acadd. Imp. et Reg. Petrop., Pat., et Georg. Florent., Brux., Neap., Mut., Lync. Rom., Societ. Philomat. Paris., Corresp.* 1 Dorset-street, Manchester-square.
- Rev. Henry Hervey Baber, M.A. *M.R.S.L. Acad. Reg. Sc. Monach. Socius.* British Museum; and Stretham, Cambridgeshire.
- Benjamin Guy Babington, M.B. 48 Finsbury-square.
- Charles Badham, M.D., Professor of Physic, Glasgow. *Coll. Reg. Med. Socius.* Glasgow.
- Francis Baily, Esq.—VICE-PRESIDENT.—*M.R.I.A. F.L.S. F.G.S. V.P.R.A.S. Acad. Amer. Art. et Sc. Bost. Socius.*—President of the Royal Astronomical Society. 37 Tavistock-place, Russell-square.
- Andrew Baird, M.D. 2 Clarges-street, Piccadilly.
- William John Bankes, Esq. 5 Old Palace-yard; and Soughton-hall, near Northupt, Flintshire, North Wales.
- Lewis, Count of Barbiano and Belgioioso.
- Peter Barlow, Esq. *F.R.A.S. M.C.P.S. Acad. Imp. Sc. Petrop. Socius.—Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Brux., Corresp.* Royal Military Academy, Woolwich (Marine Barracks).
- Rear-Admiral Sir Robert Barlow, K.C.B. Canterbury.
- Edward Barnard, Esq. *F.L.S.* 18 Downing-street.
- Charles Frederick Barnwell, Esq. M.A. *F.S.A.* 44 Woburn-place, Russell-square.
- Rev. Frederick Henry Barnwell, M.A. *F.S.A.* Bury St. Edmund's.
- John Baron, M.D. Gloucester.
- John Barrow, Esq. *F.L.S.* 21 New-street, Spring-gardens.
- Sir David Barry, M.D. K.S.A. K.T.S. *Soc. Philom. Paris. Socius.* 26 Welbeck-street.
- George Henry Law, Lord Bishop of Bath and Wells. *F.S.A.* 4 Langham-place; and Wells, Somersetshire.

- Rev. Joseph Hallet Batten, D.D. East India-college, Hertfordshire.
 William Battine, LL.D.
 Lieut. Colonel Robert Batty. 6 Connaught-square.
 Francis Bauer, Esq. *F.L.S.* Kew.
 Rev. William Frederick Baylay, M.A. *F.S.A.* Canterbury.
 Major North Ludlow Beamish. Beaumont-house, Cork.
 Sir William Beatty, Knt. M.D. *F.L.S.* Greenwich.
 Vice-Admiral Lord Amelius Beauclerk, K.C.B. G.C.H. 30 Margaret-street, Cavendish-square.
 Francis Beaufort, Esq. Captain in the Royal Navy. *F.G.S. F.R.A.S.* Admiralty; and 7 Somerset-place.
 Henry Beaufoy, Esq. *F.L.S.* South Lambeth.
 Henry Thomas de la Beche, Esq. *F.L.S. F.G.S.* Ordnance Map Office, Tower.
 Right Hon. Sir John Beckett, Bart. LL.D. 11 Stratford-place; and Somerby-park, Gainsborough.
 Frederick William Beechey, Esq. Captain in the Royal Navy. *F.R.A.S.* 18 Harley-street.
 William Beetham, Esq. *F.S.A.* Stoke Newington.
 Sir Charles Bell, K.H. *F.R.S.E. F.L.S. F.G.S.* 30 Lower Brook-street.
 John Bell, Esq. M.A. 20 Bedford-square.
 Thomas Bell, Esq. *F.L.S.* 17 New Broad-street.
 Charles James Beverly, Esq. Bethnal-green.
 Nicholas, Lord Bexley, M.A. *F.S.A. M.R.S.L.* 31 Great George-street; and Foot's Cray-place, Kent.
 James Ebenezer Bicheno, Esq. *F.L.S. F.G.S.* 8 Linden-grove, Kensington Gravel-pits.
 John Laurens Bicknell, Esq. *F.S.A.* 25 Abingdon-street.
 Robert Bingley, Esq. *F.G.S.* Royal Mint, Tower-hill; and Woodford, Essex.
 Captain Benjamin Blake. *F.G.S. F.R.A.S.* India.
 William Blake, Esq. M.A. *F.G.S.* 62 Portland-place; and Danesbury, near Welwyn, Hertfordshire.
 William John Blake, Esq. 62 Portland-place.
 Michael Bland, Esq. *F.S.A. F.L.S. F.G.S.* St. Leonard's, Hastings.
 Rev. Miles Bland, D.D. *F.S.A. F.R.A.S. M.R.S.L.* Ramsgate.
 Sir Gilbert Blane, Bart. M.D. *F.R.S.E. Soc. Reg. Sc. Gottin. Socius.—Inst. Reg. Sc. Paris., et Acad. Imp. Sc. Petrop., Corresp.* 8 Sackville-street; and Burfield, Reading, Berkshire.
 William Blane, Esq.
 Richard Blanshard, Esq. *F.S.A. M.R.A.S. M.R.S.L.* 187 Piccadilly.
 Thomas Blizard, Esq. *F.R.S.E.* Brighton.
 Sir William Blizard, Knt. *F.R.S.E. F.S.A. Soc. Reg. Sc. Gottin. Corresp.* Devonshire-square.
 George Simon Borlase, Esq. Helston, Cornwall.
 Samuel Bosanquet, Esq. 73 Lombard-street.
 John Bostock, M.D. *F.L.S. F.G.S. F.R.A.S.* 22 Upper Bedford-place.
 Rev. Joseph Bosworth, LL.D. *F.S.A. M.R.S.L. Socc. Reg. Sc. Norv., Dronth., et Gothen., Socius.* British Chaplain, Rotterdam.
 Thomas Botfield, Esq. *F.G.S.* Hopton-court, Bewdley.
 Sir William Edward Rouse Boughton, Bart. Downton-hall, Ludlow.
 Right Hon. William Sturges Bourne, M.A. 37 Brook-street; and Testwood-house, Southampton.
 Hon. Sir Courtenay Boyle, Knt. 24 Upper Berkeley-street; and Hampton-court-palace.

- William Thomas Brande, Esq., Professor of Chemistry at the Royal Institution. *F.R.S.E. F.G.S.* Royal Mint, Tower-hill.
- Thomas Shaw Brandreth, Esq. 8 Queen's-square, Bloomsbury.
- John, Marquess of Breadalbane. 21 Park-lane.
- Robert Bree, M.D. *F.S.A. Coll. Reg. Med. Socius.* 17 George-street, Hanover-square.
- Sir David Brewster, K.H. LL.D. *F.R.S.E. Hon. M.R.I.A. F.G.S. F.R.A.S. Instit. Reg. Sc. Paris. Corresp.—Soc. Reg. Sc. Götting. Socius.* Kingussie, N. B.
- William Bridgman, Esq. *F.S.A.* Frogmore, Gloucester.
- Richard Bright, M.D. *F.G.S. Acadd. Imp. Sc. Petrop., Reg. Sc. Berol. et Holm., Soc. Reg. Sc. Dan. Socius.* 11 Saville-street.
- Lieut.-General Sir Thomas Makdougall Brisbane, K.C.B. G.C.H. D.C.L. *F.R.S.E. F.R.A.S. Instit. Reg. Sc. Paris. Corresp.*—President of the Royal Society of Edinburgh. Makerstown, Kelso.
- Frederick William, Marquess of Bristol. 6 St. James's-square.
- William John Broderip, Esq. B.A. *F.L.S. V.P.G.S.* 2 Raymond-buildings, Gray's-inn.
- Benjamin Collins Brodie, Esq., Serjeant Surgeon to the King.—VICE-PRESIDENT. 14 Saville-street.
- Sir Edward Ffrench Bromhead, Bart. M.A. *F.R.S.E. F.R.A.S.* Thurlby, Lincolnshire.
- Sir Arthur Brooke de Capell Brooke, Bart. M.A. *F.L.S. F.G.S.* Oakley, Northamptonshire.
- Henry James Brooke, Esq. *F.L.S. F.G.S.* Mawbey-place, South Lambeth.
- Henry, Lord Brougham and Vaux, Lord High Chancellor of England, M.A. *Trust. Brit. Mus.—Instit. Reg. Sc. Paris. Socius.* 48 Berkeley-square; and Brougham-hall, Penrith.
- Samuel Daniel Broughton, Esq. *F.G.S.* 12 Great Marlborough-street.
- Robert Brown, Esq. D.C.L. *Hon. Mem. R.S.E., R.I.A., and C.P.S., V.P.L.S. Instit. Reg. Sc. Paris. Socius.—Acadd. Imp. Sc. Petrop., et Cæs. Nat. Cur., Reg. Sc. Holm., et Monach., Soc. Reg. Sc. Hafn., Instit. Reg. Sc. Amstelod., Socc. Sc. Harlem., Trajectin., et Phil. Nov.-Ebor. Socius.—Acadd. Reg. Sc. Berol., et Brux., Corresp.* 17 Dean-street, Soho-square.
- John, Earl Brownlow, M.A. *F.S.A. F.L.S. F.G.S. M.R.A.S.* 4 Great Stanhope-street, Park-lane.
- Isambard Kingdom Brunel, Esq. 30 Bridge-street, Blackfriars.
- Mark Isambard Brunel, Esq.—VICE-PRESIDENT.—*Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Monach., Corresp.* 53 Parliament-street.
- Walter Francis, Duke of Buccleuch, K.T. Whitehall-gardens; and Dalkeith-house, Edinburgh.
- Rev. William Buckland, D.D., Professor of Mineralogy and Geology, Oxford. *F.L.S. F.G.S. Socc. Min. Imp. Petrop., et Cæs. Nat. Cur. Mosc., Socius.* Christ-church, Oxford.
- Sir William Burnett, K.C.H. *Coll. Reg. Med. Socius.* 5 Somerset-place.
- Rev. Charles Parr Burney, D.D. *F.S.A. F.L.S. F.G.S. F.R.A.S. M.R.A.S. M.R.S.L.* Greenwich.
- John Burns, M.D. Glasgow.
- Sir William Burroughs, Bart. *M.R.A.S.*
- Rev. Edward John Burrow, D.D. *F.L.S. F.G.S.* Fitzroy-square.
- Decimus Burton, Esq. Spring-gardens; and St. Leonard's, Hastings.
- John, Marquess of Bute, M.A. *F.R.A.S.* Camden-hill, Kensington.
- Rev. George Butler, D.D. *F.S.A.*

Samuel Butler, D.D. Archdeacon of Derby.
F.S.A. Shrewsbury.

John Butter, M.D. *F.L.S.* Woodbury, near
Lymptone, Devonshire.

William Archibald Cadell, Esq. *F.R.S.E.*
F.G.S. Edinburgh.

Alexander Caldcleugh, Esq. *F.L.S. F.G.S.*
Mexico.

John Caley, Esq. *M.R.I.A. F.S.A. F.L.S.*
F.R.A.S. M.R.S.L. Exmouth-street, Spa-
fields.

William Camac, Esq. 6 Mansfield-street; and
Hastings, Sussex.

Right Hon. Lord John Douglas Edward
Henry Campbell. *F.R.S.E.* Ardencaple-
castle, Helensburgh, Dumbartonshire.

Right Hon. William Howley, D.D., Lord
Archbishop of Canterbury. *Trust. Brit.*
Mus.—F.S.A. Lambeth-palace.

Rev. Henry Card, D.D. *F.S.A.* Great Mal-
vern, Worcestershire.

Right Hon. Reginald Pole Carew. *F.S.A.*
7 New Cavendish-street; and Antony-house,
Devonport.

Hon. and Rev. Richard Carleton, M.A.
37 South-street, Grosvenor-square; and Grey-
well-hill, Odiham, Hampshire.

Sir Anthony Carlisle, Knt. *F.S.A. F.L.S.*
6 Langham-place.

Nicholas Carlisle, Esq. K.H. *Hon. M.R.I.A.*
Sec. S.A. Somerset-house.

Joseph Carne, Esq. *M.R.I.A. F.G.S.* Pen-
zance.

Joseph Constantine Carpue, Esq. 45 Upper
Charlotte-street, Fitzroy-square.

Sir Codrington Edmund Carrington, Knt.
D.C.L. *F.S.A. M.R.A.S.* 93 Jermyn-street.

Robert, Lord Carrington. *F.S.A. F.G.S.*
Whitehall-yard.

John Carstairs, Esq. Stratford, Essex.

Rev. Thomas Catton, B.D. *F.R.A.S.* St.
John's college, Cambridge.

William, Lord Cavendish, M.A. *F.G.S.* 10
Belgrave-square.

John Frederick, Earl Cawdor, B.A. *F.G.S.*
9 Grosvenor-square.

William Frederick Chambers, M.D. *Coll.*
Reg. Med. Socius. 23 a, Brook-street.

George Chandler, D.D., Dean of Chichester.
36 Mortimer-street.

Francis L. Chantrey, Esq. R.A. D.C.L.
F.R.S.E. F.S.A. F.G.S. M.R.S.L. 30
Lower Belgrave-place, Pimlico.

Colonel Sir Stephen Remnant Chapman, C.B.
K.C.H. Royal Engineers. Bermudas.

Charles William, Earl of Charleville.
M.R.I.A. F.S.A. 14 Cavendish-square.

Lewis Andrew de la Chaumette, Esq. *F.S.A.*
M.R.S.L. 29 Bedford-place, Russell-square;
and Lordship-lodge, Tottenham.

Edward Maltby, Lord Bishop of Chichester.
F.S.A. 14 Old-square, Lincoln's-inn; and
Chichester-palace, Sussex.

John George Children, Esq.—*SECRETARY.*—
F.R.S.E. F.S.A. F.L.S. F.G.S. British
Museum.

Samuel Hunter Christie, Esq. M.A. *M.C.P.S.*
Soc. Philom. Paris. Corresp. Royal Military
Academy, Woolwich.

Francis Almaric, Lord Churchill. Ham-com-
mon, Richmond.

Lord Henry John Spencer Churchill. *F.L.S.*
Kensington-palace.

James Clark, M.D. 21 George-street, Han-
over-square.

Sir Charles Mansfield Clarke, Bart. M.D.
10 Saville-street; and Dunham-lodge, Swaff-
ham, Norfolk.

Rev. James Stanier Clarke, LL.D. 25 Upper
Phillimore-place, Kensington.

Loftus Longueville Clarke, Esq. M.A. India.

- William Stanley Clarke, Esq. *F.G.S.* East India-house.
- Sir George Clerk, Bart. *D.C.L. F.R.S.E. F.G.S.* Penyuick, Edinburghshire.
- Major F. H. Shadwell Clerke, K.H. 8 Trevor-terrace, Knightsbridge.
- William Clift, Esq. *F.G.S.* Royal College of Surgeons, Lincoln's-inn-fields.
- Marshall Waller Clifton, Esq. Boulogne.
- John Brinkley, Lord Bishop of Cloyne. *Hon. M.R.S.E. Instit. Reg. Sc. Paris. Corresp.*—President of the Royal Irish Academy. Cloyne-palace, Cork.
- Right Hon. Sir George Cockburn, G.C.B. G.C.H. *F.R.A.S.* 4 Whitehall.
- Rev. Henry Coddington, M.A. *F.G.S. F.R.A.S.* Trinity-college, Cambridge.
- Vice Admiral Sir Edward Codrington, G.C.B. 92 Eaton-square; and Hampton-lodge, Brighton.
- Lieut. Colonel Thomas Colby, Royal Engineers, LL.D. *F.R.S.E. M.R.I.A. F.G.S. F.R.A.S. M.R.A.S.* Ordnance Map Office, Tower; and Depôt Ordnance Survey of Ireland, Dublin.
- William Willoughby, Viscount Cole. *F.G.S.* 20 Jermyn-street; and Florence-court, Fermagh, Ireland.
- Henry Thomas Colebrooke, Esq. *F.R.S.E. F.L.S. F.G.S. F.R.A.S. M.R.A.S. Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Monach., Socius.* 30 Argyll-street.
- Sir James Edward Colebrooke, Bart. *F.G.S. M.R.A.S.* 30 Argyll-street; and Colebrooke-park, Tunbridge.
- Edward Coleman, Esq. Veterinary-college, St. Pancras.
- Charles Collier, Esq. Bombay.
- George Lewis Newnham Collingwood, Esq.
- James Nisbet Colquhoun, Esq. Captain in the Royal Artillery. Woolwich.
- Rev. William Daniel Conybeare, M.A. *F.G.S. Instit. Reg. Sc. Paris. Corresp.* Sully, near Cardiff.
- John Cooke, M.D. *F.S.A. Coll. Reg. Med. Socius.* 71 Gower-street; and Whetstone, Middlesex.
- Sir Astley Paston Cooper, Bart. *Soc. Reg. Sc. Gottin. Corresp.* 39 Conduit-street; and Gadebridge, Hemel-Hempstead.
- Bransby Blake Cooper, Esq. 2 New-street, Spring-gardens.
- Charles Purton Cooper, Esq. LL.D. New Boswell-court, Lincoln's-inn.
- Rev. John Corrie. Woodville, near Birmingham.
- William Cotton, Esq. *F.S.A.* 3 Crosby-square, Bishopsgate-street; and Walwood-house, Leytonstone.
- Peter Leopold, Earl Cowper. 11 Little Maddox-street.
- Philip Cecil Crampton, Esq. *D.C.L.* Westminster-hotel.
- John Crawford, Esq. *F.L.S. F.G.S. M.R.A.S.* Wilton-terrace, Knightsbridge.
- Rev. Daniel Cresswell, D.D. Enfield, Middlesex.
- Sir Alexander Crichton, Knt. M.D. Grand Cross of St. Anne and St. Vladimir. *F.L.S. F.G.S. Acad. Imp. Sc. Petrop., et Soc. Hist. Nat. Mosc., Socius.—Soc. Reg. Sc. Gottin. Corresp.* Seal Chart, near Sevenoaks, Kent.
- Sir John Croft, Bart. K.T.S. *D.C.L. Acad. Reg. Olyssip. Socius.* 45 Brook-street; and Cowling-hall, Yorkshire.
- Right Hon. John Wilson Croker, LL.D. 14 Duke-street, Westminster.
- Rev. Alexander Crombie, LL.D. *M.R.S.L.* 12 York-terrace, Regent's-park.
- William Cubitt, Esq. *M.R.I.A. F.R.A.S.* 16 Parliament-street.

Hon. Lieut.-General John Leslie Cuming.
 Rev. James Cumming, M.A., Professor of
 Chemistry, Cambridge.—VICE-PRESIDENT.
 —*F.G.S.* Cambridge.

John Dalton, Esq. D.C.L. *Instit. Reg.
 Sc. Paris., Socius.—Acad. Reg. Sc. Monach.,
 Socius.* Philosophical Society, Manchester.

Edmund Robert Daniell, Esq. *F.R.A.S.
 Sec. R.I.* 23 Torrington-square.

John Frederick Daniell, Esq., Professor of
 Chemistry, King's-college, London. 30
 Gower-street.

Edward, Earl of Darnley. 46 Berkeley-
 square; and Cobham-hall, Kent.

William, Earl of Dartmouth, B.A. *F.S.A.*
 1 St. James's-square.

Robert Waring Darwin, M.D.

Charles Giles Bridle Daubeny, M.D. Ald-
 rich's Professor of Chemistry, Oxford.
F.L.S. F.G.S. Coll. Reg. Med. Socius.
 Oxford.

Griffith Davies, Esq. Palmer-terrace, Isling-
 ton.

Thomas Stephens Davies, Esq. *F.R.S.E.
 F.R.A.S.* Bath.

John Francis Davis, Esq. Canton, China.

Richard Hart Davis, Esq. 38 Conduit-street.

Edmund Davy, Esq., Professor of Chemistry
 to the Royal Dublin Society. *M.R.I.A.*
 Dublin.

John Davy, M.D. Malta.

Rev. Martin Davy, D.D. *F.S.A.* Caius-col-
 lege, Cambridge.

James Dawkins, Esq. *F.S.A.* Ham-common,
 Richmond.

Rev. William Dealtry, D.D. *F.R.A.S.* Clap-
 ham-common.

Right Hon. Sir Thomas Denman, Knt. 50
 Russell-square; and Stoney Middleton, Der-
 byshire.

John Dickenson, Esq. *F.S.A. F.G.S.* 32 De-
 vonshire-place; and Grundisburgh-hall, Wood-
 bridge, Suffolk.

Lewis Weston Dillwyn, Esq. *F.L.S. F.G.S.*
 45 Bridge-street, Westminster; and Penlle-
 gare, near Swansea.

John Disney, Esq. The Hyde, near Ingate-
 stone, Essex.

Rev. Richard Dixon, M.A.

George Dollond, Esq. *F.R.A.S.* 59 St.
 Paul's Churchyard; and North-terrace,
 Camberwell.

Lieut.-Gen. Sir Rufane Shaw Donkin, K.C.B.
 G.C.H. *F.G.S. M.R.S.L.* 33 Park-street,
 Grosvenor-square; and Lower Caversham,
 Oxfordshire.

George Douglas, Esq. Chilston, Kent.

Major-General Sir Howard Douglas, Bart.
 C.B. K.S.C. D.C.L. *F.S.A.* Ramsgate.

William Robert Keith Douglas, Esq. 95
 Eaton-square.

Rev. George D'Oyly, D.D. Rectory, Lam-
 beth.

Rev. Henry Drury, M.A. *F.S.A.* Harrow.

Thomas Reynolds, Lord Ducie. *F.S.A.* 2 Sea-
 more-place, Curzon-street.

Sir George Duckett, Bart. M.A. *F.S.A.*
F.G.S. M.R.A.S. 28 Norfolk-street, Park-
 lane; and Roydon, near Ware, Hertfordshire.

Alexander Duncan, Esq.

Robert Adam Dundas, Esq. 97 Eaton-square.

Francis, Lord de Dunstanville, M.A. South-
 place, Knightsbridge.

Major-General Sir Benjamin D'Urban, K.C.B.
 K.C.H. K.T.S. Cape of Good Hope.

Henry Earle, Esq. 28 George-street, Hanover-
 square.

Right Hon. Sir Edward Hyde East, Bart.
M.R.A.S. Addlesthorpe-house, Chipping-
 Norton, Oxfordshire.

- Hugh, Viscount Ebrington. 17 Grosvenor-square.
- Lovell Edgeworth, Esq. Edgeworth's-town, Ireland.
- Neil Benjamin Edmonstone, Esq. 49 Portland-place.
- W. T. Edwards, M.D. Rue Louis-le-Grand No. 26, Paris.
- Sir Philip de Malpas Grey Egerton, Bart. *F.G.S.* Oulton-park, Cheshire.
- George, Earl of Egremont. *F.S.A.* 4 Grosvenor-place.
- John, Earl of Eldon, D.C.L. *F.S.A.* 1 Hamilton-place.
- Sir William Elford, Bart. *F.L.S.* The Priory, Totnes, Devonshire.
- Sir William Francis Elliott, Bart. Stobb's Castle, and Wells, N.B.
- Rev. Charles Boileau Elliott. Godalming, Surrey.
- John Elliotson, M.D. *Coll. Reg. Med. Socius.* 37 Conduit-street.
- John Ellis, Esq. *F.L.S.*
- Sir Henry Ellis, K.H. B.C.L. Principal Librarian of the British Museum. *Sec. S.A.* British Museum.
- Right. Hon. Henry Ellis. *F.G.S.*
- Howard Elphinstone, Esq. M.A. *F.G.S.* 19 Eaton-place, Belgrave-square.
- Bowyer Edward Sparke, Lord Bishop of Ely. *F.S.A.* 37 Dover-street; and The Palace, Ely, Cambridgeshire.
- Captain George Everest, Bengal Artillery. *F.G.S. F.R.A.S. M.R.A.S.* India.
- Michael Faraday, Esq. D.C.L. Fullerian Professor of Chemistry in the Royal Institution of Great Britain. *M.R.I. F.G.S. M.C.P.S. Acad. Imp. Sc. Petrop. Socius Honor.—Instit. Reg. Sc. Paris. Corresp.—Soc. Reg. Sc. Berol., Hafn., Soc. Georg. Florent., et Soc. Philom. Paris., Socius.* 21 Albemarle-street.
- Charles, Lord Farnborough, G.C.B. *Trust. Brit. Mus. F.S.A. F.L.S. M.R.S.L.* Bromley-hill, Kent.
- Rev. James Farquharson. Alford, Aberdeenshire.
- Robert Ferguson, Esq. *F.R.S.E. F.G.S.* 18 Portman-square; and Raith, Kirkaldy, Fifeshire.
- Rev. George Fisher, M.A. *F.R.A.S. H. M.* S. Victory, Portsmouth.
- William Henry Fitton, M.D. *F.L.S. F.G.S. F.R.A.S. Coll. Reg. Med. Socius.* 53 Upper-Harley-street; and Highwood-hill, Hendon, Middlesex.
- William Vesey, Lord Fitzgerald and Vesey. *M.R.I.A.* New-street, Spring-gardens.
- Charles William, Earl Fitzwilliam. *F.S.A. F.G.S.* Mortimer-house, Grosvenor-place.
- Sir Robert FitzWygram, Bart. *M.R.I.A. F.S.A.* 10 Connaught-place.
- James David Forbes, Esq. Professor of Natural Philosophy in the University of Edinburgh. *F.R.S.E. F.G.S.* Greenhill, near Edinburgh.
- John Forbes, M.D. Chichester.
- William Nairn Forbes, Esq. *F.G.S.*
- Rev. Josiah Forshall, M.A. *F.S.A. M.R.S.L.* British Museum.
- Edward Forster, Esq. *V.P.L.S.* 11 Mansion-house-street; and Hale End, Essex.
- Richard Fowler, M.D. *F.S.A.* Salisbury.
- James Franck, M.D. *F.G.S. Coll. Reg. Med. Socius.* 26 Hertford-street.
- Captain James Franklin. *F.G.S. M.R.A.S.* Bengal.
- Sir John Franklin, Knt. Captain in the Royal Navy, D.C.L. *F.G.S. F.R.A.S. Soc. Geogr. Paris. Corresp.*
- William Franks, Esq. M.A. Wood-hill, Hatfield, Hertfordshire.

- Colonel Sir Augustus Simon Frazer, K.C.B.
Royal Artillery. Royal Arsenal, Woolwich.
- Cypriano Ribeiro Freire, Knight of St. Iago
and of Christ. *F.S.A. Acad. Reg. Sc. Olyssip. Socius.*
- Matthew Curling Friend, Esq. Lieutenant in
the Royal Navy. George Town, Van Diemen's Land.
- John Gage, Esq. *F.S.A. F.L.S.* 10 Old-square, Lincoln's-inn.
- Rev. Samuel John Gardiner, M.A.
- Right Hon. Sir William Garrow, Knt.
27 Great George-street, Westminster.
- George, Lord Garvagh. *F.S.A.* 26 Portman-square.
- Sir William Gell, Knt. *F.S.A. Acad. Reg. Sc. Berol. Socius Honor.* Rome.
- Sir George Smith Gibbes, Knt. M.D. *F.L.S. Coll. Reg. Med. Socius.* Bath.
- Davies Gilbert, Esq. D.C.L.—VICE-PRESIDENT.—*Hon. M.R.S.E. Hon. M.R.I.A. F.S.A. F.L.S. V.P.G.S. F.R.A.S.*—President of the Royal Geological Society of Cornwall. 27 Gower-street; East Bourn, Sussex; and Tredrea, Penzance, Cornwall.
- John Gillies, LL.D. *F.R.S.E. F.S.A. Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Gotting., Corresp.* Clapham.
- George, Earl of Glasgow, G.C.H. *F.S.A.* Camden-hill, Kensington.
- James Murray, Lord Glenlyon, K.C.H.
- George Glover, M.A., Archdeacon of Sudbury.
- John Goldingham, Esq. *F.R.A.S. M.R.A.S.* Worcester.
- Isaac Lyon Goldsmid, Esq. *F.S.A. F.L.S. F.G.S. F.R.A.S. M.R.S.L.* Dulwich-hill-house, Camberwell.
- Benjamin Gompertz, Esq. *F.R.A.S.* Kennington-terrace, Vauxhall.
- Edmund Goodenough, D.D. Dean of Wells.
The Deanery, Wells.
- Lieut.-General Sir James Willoughby Gordon, Bart. K.C.B. G.C.H. 50 Devonshire-street, Portland-place.
- Thomas Gordon, Esq. Cairness, N.B.
- Henry Percy Gordon, Esq. M.A. St. Peter's-college, Cambridge.
- Right Hon. Henry Goulburn. 1 Upper Berkeley-street.
- Right Hon. Sir James R. G. Graham, Bart.
Admiralty; and Netherby, Cumberland.
- Right Hon. Charles Grant, D.C.L. *M.R.S.L.*
11 Great George-street, Westminster; and Glenelge, Inverness.
- Lewis Alexander Grant, Esq.
- Augustus Bozzi Granville, M.D. *F.L.S. F.G.S. M.R.A.S. Acad. Reg. Sc. Brus. Socius.—Acad. Reg. Sc. Taurin.: Acad. Luc., et Patav.: Socc. Georg. Florent., Ital. Vienn., Sc. Nat. Neap., Athen. Ven., Philomath. Paris., Socius.—Acad. Imp. Sc. Petrop. Corresp.* 16 Grafton-street, Bond-street; and Rosemont, Great Missenden, Buckinghamshire.
- William Gravatt, Esq.
- Francis, Lord Gray. Twickenham, Middlesex; and Kinfauns Castle, Perth.
- John Edward Gray, Esq. *F.G.S. M.R.S.L.*
British Museum; and Eliot Vale, Blackheath.
- Joseph Henry Green, Esq. Professor of Surgery, King's-college, London. *F.G.S.* 46 Lincoln's-inn-fields.
- George Bellas Greenough, Esq. *F.L.S. F.G.S. M.R.A.S.* President of the Geological Society. Grove-house, Regent's-park.
- Richard Gregory, Esq. *F.S.A.* 56 Berners-street.
- Woronzow Greig, Esq. M.A. 2 Mitre-court-buildings, Temple.

- William Wyndham, Lord Grenville, D.C.L. Chancellor of the University of Oxford. *Trust. Brit. Mus. F.S.A. F.G.S.*
- Rev. Richard Greswell, M.A. Worcester-college, Oxford.
- Sir Thomas Grey, Knt. M.D. *F.L.S.* Ramsgate.
- John Griffiths, Esq.
- Captain John Grover. 12 Egremont-place, King's-cross.
- Josiah John Guest, Esq. *F.G.S.* Dowlais Iron Works, Glamorganshire.
- John Lewis Guillemard, Esq. M.A. *F.L.S. F.G.S. M.R.A.S. Soc. Amer. Philad. Socius.* 27 Gower-street; and Woodford, Essex.
- Hudson Gurney, Esq. *V.P.S.A. M.R.S.L.* 9 St. James's-square; and Keswick-hall, near Norwich.
- George James Guthrie, Esq. 2 Berkeley-street, Piccadilly.
- Rev. John Hailstone, M.A. *F.L.S. F.G.S.* Trumpington, Cambridgeshire.
- Sir Henry Halford, Bart. G.C.H. *Trust. Brit. Mus. F.S.A.*—President of the Royal College of Physicians. 16 Curzon-street; and Wistow-hall, near Market-Harborough.
- Basil Hall, Esq. Captain in the Royal Navy, D.C.L. *F.R.S.E. F.G.S. F.R.A.S. M.R.A.S.* Rome.
- Sir John Hall, Bart. *F.R.S.E. F.G.S.* Dunglass, Dunbar, Haddingtonshire.
- Marshall Hall, M.D. *F.R.S.E.* 14 Manchester-square.
- Thomas Henry Hall, Esq. M.A. 45 Guilford-street.
- Henry Hallam, Esq. M.A. *V.P.S.A. F.G.S. M.R.S.L.* 67 Wimpole-street.
- Alexander, Duke of Hamilton and Brandon. *F.S.A.* Hamilton-house, Lanarkshire.
- Rev. Henry Parr Hamilton, M.A. *F.R.S.E. F.G.S. F.R.A.S.* Trinity-college, Cambridge.
- William Richard Hamilton, Esq. *V.P.S.A. M.R.S.L. Acad. Reg. Sc. Berol. Socius Honor.* 22 Grafton-street, Bond-street.
- Sir Thomas Hanmer, Bart. Hanmer-hall, Flintshire.
- Rev. William Venables Vernon Harcourt, M.A. *F.G.S.* Wheldrake, near York.
- Philip Hardwick, Esq. *F.S.A.* 60 Russell-square.
- Philip, Earl of Hardwicke, K.G. D.C.L. *Trust. Brit. Mus. F.S.A. F.G.S.* 3 St. James's-square.
- Major-General Thomas Hardwicke. *M.B.I.A. F.L.S. M.R.A.S.* The Lodge, South Lambeth.
- Francis George Hare, Esq.
- John Scandret Harford, Esq. D.C.L. 38 Conduit-street.
- William Snow Harris, Esq. Plymouth.
- Sir George Harrison, Knt. K.C.H. *F.S.A.* 4 Spring-garden-terrace.
- George Harvey, Esq. *F.R.S.E. F.L.S. F.G.S. F.R.A.S.* Plymouth.
- Henry Harvey, Esq. Hill-house, Streatham, Surrey.
- John Harwood, M.D. *F.L.S.* Professor of Natural History, Royal Institution. St. Leonard's, Hastings.
- Rev. Henry Hasted, M.A. *F.L.S.* Bury, Suffolk.
- Charles Hatchett, Esq. *F.R.S.E. F.S.A. F.L.S. Instit. Reg. Sc. Paris. Corresp.—Acad. Reg. Sc. Monach., et Soc. Oecon. Petrop., Socius.* Belle-Vue-house, Chelsea; and Bullington, Lincolnshire.
- Sir Graves Chamney Haughton, Knt. M.A. *Sec. R.A.S.* 28 Dorset-square.

- Edward Hawkins, Esq. *F.S.A. F.L.S.*
British Museum.
- John Hawkins, Esq. Quay-house, Devonshire.
- John Hawkins, Esq. Bignor Park, Petworth,
Sussex.
- John Heywood Hawkins, Esq. *M.A. F.G.S.*
8 Suffolk-street; and Bignor-park, Petworth,
Sussex.
- Alexander Hay, M.D.
- Robert William Hay, Esq. *F.S.A.* 21 Queen-
street, May-Fair.
- George Crauford Heath, Esq. Cambridge.
- William Heberden, M.D. *Coll. Reg. Med.*
Socius. 30 Pall-mall.
- James Henderson, Esq. Boulogne.
- Henry Hennell, Esq. Apothecaries'-hall,
Bridge-street, Blackfriars.
- William Henry, M.D. *F.G.S.* Manchester.
- Sir John Frederick William Herschel,
K.H. *M.A. F.R.S.E. M.R.I.A. F.G.S.*
V.P.R.A.S. M.C.P.S. Instit. Reg. Sc.
Paris. Corresp.—Acadd. Imp. Sc. Petrop.,
et Reg. Sc. Brux.: Socc. Reg. Sc. Berol.,
Hafn., Harl. et Neap.: Acadd. Lync. Romæ,
Pad., Bonon., Panorm., Gioen. Catan. et
Divion., ex intim.: Socc. Philom. Paris,
Ital. Mut., Helvet., Socius.—Soc. Reg. Sc.
Gotting. Corresp. Cape of Good Hope.
- George Hibbert, Esq. *F.S.A. F.L.S.* 3 Wey-
mouth-street.
- Rev. John Philips Higman, M.A. *F.G.S.*
F.R.A.S. Trinity-college, Cambridge.
- Charles Hoare, Esq. *F.S.A.* 37 Fleet-street.
- Henry Hugh Hoare, Esq. *F.S.A.* 7 York-
street, St. James's.
- Sir Richard Colt Hoare, Bart. *F.S.A. F.L.S.*
Stourhead, Wiltshire.
- Right Hon. Sir John Cam Hobhouse, Bart.
M.A. 42 Berkeley-square.
- Thomas Hoblyn, Esq. *F.L.S.* 125 Sloane-
street.
- Joseph Hodgson, Esq. Crescent, Birmingham.
- Robert Hodgson, D.D. Dean of Carlisle.
F.C.S. 15 Grosvenor-street; and Hilling-
don, Uxbridge.
- Robert Holford, Esq. 1 Lincoln's-inn-fields.
- Henry Richard Vassall, Lord Holland.
F.S.A. 30 Old Burlington-street.
- Henry Holland, M.D. *F.L.S. F.G.S. Coll.*
Reg. Med. Socius. 25 Brook-street.
- James Holman, Esq. Lieutenant in the
Royal Navy, K.W. *F.L.S.* Windsor.
- Sir Everard Home, Bart. Commander in the
Royal Navy. *F.S.A.*
- William Jackson Hooker, LL.D. Regius
Professor of Botany, Glasgow. *F.S.A.*
F.L.S. F.G.S. Acad. Cas. Nat. Cur.
Socius. Glasgow.
- James Hope, M.D. 13 Lower Seymour-street.
- Thomas Charles Hope, M.D. Professor
of Chemistry, Edinburgh. *V.P.R.S.E.*
F.L.S. Edinburgh.
- Leonard Horner, Esq. *F.R.S.E. V.P.G.S.*
Soc. Batav. Sc. Harlem. Socius. Edinburgh.
- James Horsburgh, Esq. *F.R.A.S. Acad.*
Imp. Sc. Petrop. Corresp. East India-house;
and Herne-hill, Surrey.
- Thomas Horsfield, M.D. *F.L.S. F.G.S.*
M.R.A.S. Lower Islington.
- Right Hon. Sir Robert John Wilmot Horton,
G.C.H. *M.A.* Ceylon.
- David Hosack, M.D. *F.R.S.E. F.L.S.*
New York.
- Hon. Colonel Fulk Greville Howard. *F.S.A.*
16 Grosvenor-square.
- Luke Howard, Esq. Ackworth Villa, Pomfret.
- Sir Abraham Hume, Bart. *F.S.A. F.L.S.*
F.G.S. M.R.A.S. 31 Hill-street, Berkeley-
square.
- Joseph Hume, Esq. 6 Bryanstone-square.
- Rev. George Hunt, M.A. *F.S.A.* Egg Buck-
land, near Plymouth.

- Rev. James Devereux Hustler, B.D. Easton Rectory, near Thetford, Norfolk.
- Captain George Henry Hutchinson, Bengal. Alexander Copland Hutchinson, Esq. *F.R.S.E.* 3 Duchess-street, Portland-place.
- Sir Robert Harry Inglis, Bart. LL.D. *F.S.A. F.R.A.S.* 11 Manchester-buildings; and Battersea-rise, Clapham.
- James Ivory, Esq. K.H. M.A. *Instit. Reg. Sc. Paris., et Soc. Reg. Sc. Gotting., Corresp.* 20 Southampton-street, Pentonville.
- William Jacob, Esq. 31 Cadogan-place, Sloane-street.
- Robert Jameson, Esq. Regius Professor of Natural History, Edinburgh. *F.R.S.E. Hon. M.R.I.A. F.L.S. F.G.S. Acad. Reg. Sc. Neap.: Socc. Reg. Sc. Dan., Imp. Hist. Nat. Mosc., Hist. Nat. Veter., et Paris., Philom. Paris., Amer. Philad., Phil. et Hist. Nov.-Ebor., Socius: Acad. Reg. Sc. Berol. Corresp.* Edinburgh.
- Joseph Jekyll, Esq. M.A. *F.S.A.* 23 New-street, Spring-gardens.
- Rev. Philip Jennings, D.D. Hampstead-green.
- James Rawlins Johnson, M.D. *F.L.S.* 24 Coleshill-street, Pimlico; and Bath.
- Right Hon. Sir Alexander Johnston, Knt. *F.S.A. F.L.S.* 19 Great Cumberland-place; and York-house, Twickenham.
- John Johnstone, M.D. *Coll. Reg. Med. Socius.* Birmingham.
- Captain Henry Kater. *M.R.I.A. M.R.A.S. Instit. Reg. Sc. Paris. Corresp.—Acad. Reg. Sc. Holm., Soc. Reg. Sc. Dan., Soc. Art. et Sc. Ultraj., et Acad. Sc. et Art. Bost., Socius.* 12 York-gate, Regent's-park.
- John Kidd, M.D. Regius Professor of Medicine, and Aldrich's Professor of Anatomy, Oxford. *F.G.S. Coll. Reg. Med. Socius.* Oxford.
- Philip Parker King, Esq. Captain in the Royal Navy. *F.L.S.* Dunheved, New South Wales.
- Rev. William Kirby, M.A. *F.L.S. F.G.S. Acad. Cæs. Nat. Cur., et Soc. Nat. Scrutat. Berol., Socius.* Barham, near Ipswich.
- James Lewis Knight, Esq. *F.S.A.* 1 Old-square, Lincoln's-inn; and Highwood-hill, Hendon, Middlesex.
- Thomas Andrew Knight, Esq. *Trust. Brit. Mus. F.L.S.*—President of the Horticultural Society. Downton-castle, near Ludlow, Herefordshire.
- Sir Francis Charles Knowles, Bart. M.A. *F.R.A.S.* 39 Park-street, Grosvenor-square; and Old Windsor, Berkshire.
- John Knowles, Esq. 34 Bridge-street, Blackfriars.
- Charles Konig, Esq. K.H.—FOREIGN SECRETARY.—*F.L.S. Acad. Reg. Sc. Monach. Socius.—Acad. Imp. Sc. Petrop., et Soc. Reg. Gotting., Corresp.—Soc. Hist. Nat. Mosc. Socius.—Soc. Veterav. Sodalis.* British Museum.
- Aylmer Bourke Lambert, Esq. *Hon. M.R.I.A. F.S.A. V.P.L.S. F.G.S. Acadd. Cæs. Nat. Cur. et Reg. Sc. Madrit., Socius.* 26 Grosvenor-street; and Boyton-house, Wiltshire.
- Henry, Marquess of Lansdowne, D.C.L. *Trust. Brit. Mus. M.R.S.L.* 54 Berkeley-square; and Bowood-park, Wiltshire.
- Rev. Dionysius Lardner, LL.D. *F.R.S.E. M.R.I.A. Hon. M.C.P.S.* 122 Regent-street.
- John Latham, M.D. *F.S.A. F.L.S. Acad.*

- Reg. Sc. Holm., Acad. Cæs. Nat. Cur., et Soc. Nat. Scrutat. Berol., Socius.* Winchester.
 John Latham, M.D. *F.L.S. Coll. Reg. Med. Socius.* Bradwall-hall, Cheshire.
 William Lawrence, Esq. 18 Whitehall-palace.
 Rev. William Lax, M.A. Lowndes's Professor of Astronomy and Geometry, Cambridge. St. Ibbs, Hitchin, Hertfordshire.
 William Elford Leach, M.D. *F.L.S. Acad. Cæs. Nat. Cur. Socius.—Acad. Reg. Sc. Tawin. Corresp.*
 Lieut.-Colonel William Martin Leake. *M.R.S.L. Acad. Reg. Sc. Berol. Socius. Honor.* 26 Nottingham-place.
 John Lee, LL.D.—*Treas. R.A.S.* 5 College, Doctors'-commons; and Hartwell-house, near Aylesbury, Buckinghamshire.
 Robert Lee, M.D. 14 Golden-square.
 John George Shaw Lefevre, Esq. M.A. 7 Fleet-street; and Battersea, Surrey.
 Thomas Legh, Esq. D.C.L. 3 Cumberland-street; and Lyme-park, Cheshire.
 Sir Charles Lemon, Bart. 46 Charles-street, Berkeley-square; and Carclew, near Falmouth, Cornwall.
 John Lihou, Esq. Captain in the Royal Navy. Guernsey.
 John Jebb, Lord Bishop of Limerick. *M.R.S.L.* Limerick.
 John Kaye, Lord Bishop of Lincoln. Cambridge; and Buckden-palace, Huntingdonshire.
 John Lindley, Esq. *F.L.S. F.G.S. Acad. Cæs. Nat. Cur. et Soc. Phil. Nov.-Ebor. Soc. Honor.* 21 Regent-street.
 Joseph Jackson Lister, Esq. Upton, Essex.
 Edward Lloyd, Esq. Captain in the Royal Navy.
 John Augustus Lloyd, Esq. Mauritius.
 Edward Hawke Locker, Esq. *F.S.A.* Greenwich-hospital.
 William, Viscount Lowther. *F.S.A.* 14 (A) Albany; and 5 Cleveland-row.
 Sir John William Lubbock, Bart. *F.L.S. F.G.S. F.R.A.S.* 23 St. James's-place.
 John William Lubbock, Esq. M.A.—VICE-PRESIDENT AND TREASURER. *F.L.S. F.R.A.S.* 29 Eaton-place, Belgrave-square.
 Rev. Francis Lunn, B.A. Butleigh, Glastonbury.
 Edmund Henry Lushington, Esq. M.A. Crown-office, Temple; and Park-house, near Maidstone.
 Charles Lyell, jun. Esq. M.A. *F.L.S. For. Sec. G.S.* 16 Hart-street, Bloomsbury.
 John Singleton, Lord Lyndhurst, M.A. 6 Hyde-park-terrace.
 Rev. Daniel Lysons, M.A. *F.S.A. F.L.S.* Rodmarton, Cirencester.
 James Macartney, M.D. Professor of Anatomy, Trinity-college, Dublin. *F.L.S.* Dublin.
 Zachary Macaulay, Esq. 44 Bernard-street, Russell-square.
 George, Earl of Macclesfield. *F.R.A.S.* 9 Conduit-street.
 Sir James MacGrigor, Bart. *F.R.S.E. Coll. Reg. Med. Socius.* Camden-hill, Kensington.
 Charles Macintosh, Esq.
 Charles Mackenzie, Esq. *F.L.S.* Havana.
 Sir George Steuart Mackenzie, Bart. *F.R.S.E.* Coul, Ross-shire.
 Rev. John William Mackie, M.A. 23 Gloucester-place, New-road.
 William Alexander Mackinnon, Esq. M.A. *F.S.A. F.G.S.* 4 Hyde-park-place; and Portwood-house, near Southampton.
 Thomas Maclear, Esq. *F.R.A.S.* Astronomer Royal at the Cape of Good Hope.
 Alexander MacLeay, Esq. *F.L.S. Acad. Reg.*

- Se. Holm. Socius.—Acad. Reg. Sc. Taurin. Corresp.* Sydney, New South Wales.
- William Macmichael, M.D. *F.L.S. Coll. Reg. Med. Socius.* 43 Hertford-street, Mayfair.
- Sir Frederick Madden, K.H. *F.S.A.* British Museum.
- Rev. John Maddy, D.D. *F.S.A. F.R.A.S.* 14 Argyll-street; and Somerton, Bury St. Edmund's.
- Sir George Magrath, Knt. M.D. *M.R.I.A. F.L.S.* Plymouth.
- Philip Henry, Viscount Mahon, B.A. 12 Albemarle-street; and Chevening-place, Kent.
- Ebenezer Fuller Maitland, Esq. *F.S.A.* 3 Bryanstone-square; and Park-place, Henley-on-Thames, Oxfordshire.
- Ashhurst Majendie, Esq. *F.G.S.* Hedingham-castle, Essex.
- Marquess Lewis Malaspina de Sannazaro.
- Rev. Thomas Robert Malthus, M.A. *M.R.S.L. Acad. Imp. Sc. Petrop. Socius.* East India-college, Hertfordshire.
- Captain George William Manby. Yarmouth.
- James Mangles, Esq. Captain in the Royal Navy. 41 York-chambers, St. James's-street.
- William, Earl of Mansfield. *F.S.A.* 50 Portland-place; and Caen-wood, Middlesex.
- Gideon Mantell, Esq. *F.L.S. F.G.S.* Lewes, Sussex.
- James Heywood Markland, Esq. *F.S.A.* 14 Whitehall-place.
- Frederick Marryatt, Esq. Captain in the Royal Navy. *F.L.S.* Wimbledon.
- William Marsden, Esq. LL.D. *M.R.I.A. F.S.A. M.R.A.S. Soc. Phil. Nov.-Ebor. Socius.* 50 Queen Anne-street; and Edgegrove, near Watford, Hertfordshire.
- Thomas James Mathias, Esq. *F.S.A.* Naples.
- William George Maton, M.D. *F.S.A.* *V.P.L.S. Coll. Reg. Med. Socius.—Acad. Reg. Sc. Holm., et Soc. Med. Suec., Socius.* 7 New-street, Spring-gardens.
- John Maxwell, Esq. Pollock, Renfrewshire.
- John Thomas Mayne, Esq. *F.S.A. Soc. Phil. Neap. Socius.* Teffont-house, Wiltshire.
- Rev. Charles Mayo, B.D. *F.S.A.* Colesgrove, near Cheshunt, Hertfordshire.
- Herbert Mayo, Esq. Professor of Anatomy, King's-college, London. 19 George-street, Hanover-square.
- Alexander Melville, Esq. 16 Upper Harley-street.
- Robert, Viscount Melville, K.T. *F.R.A.S.* Wimbledon, Surrey.
- Lieut.-Colonel George Miller, C.B. 2 Stone-buildings, Lincoln's-inn.
- William Taylor Money, Esq. Venice.
- Major Edward Moor, *F.S.A. M.R.A.S.* Bealings, near Woodbridge, Suffolk.
- César Moreau, Esq. *Acadd. Reg. Divion., Burd., et Masil., Socius.* Paris.
- Charles Morgan, Esq. *F.S.A. F.L.S.* Pall-mall; and Tredegar-house, near Newport, Monmouthshire.
- Charles Octavius Morgan, Esq. M.A. *F.S.A.* Tredegar-park, Monmouthshire.
- James Morier, Esq. 22 Charles-street, Berkeley-square.
- John, Earl of Morley. Kent-house, Knights-bridge.
- George Paulet Morris, M.D. 7. Prince's-court, Westminster.
- John Carnac Morris, Esq.
- Rev. Robert Morrison, D.D. Canton, China.
- Joseph William Moss, M.B. Dudley.
- Richard, Earl of Mount-Edgcumbe, D.C.L. *F.S.A.* Richmond-hill, Surrey.
- Richard Zachary Mudge, Esq. Captain in the Royal Engineers. Ordnance Map-Office, Tower.

- George, Earl of Munster. *M.R.A.S. M.R.S.L.*
13 Belgrave-street; and Upper-lodge, Bushy-park, Middlesex.
- Roderick Impey Murchison, Esq. 3 Bryanstone-place, Bryanstone-square.
- Thomas Murdoch, Esq. *F.S.A.* 8 Portland-place.
- Right Hon. Sir George Murray, G.C.B. G.C.H. K.T.S. 5 Belgrave-square; and Bleadon, Perthshire.
- William Chadwell Mylne, Esq. *F.R.A.S.* New River-Head.
- Henry Napier, Esq. Captain in the Royal Navy.
- Macvey Napier, Esq. *F.R.S.E.* Edinburgh.
- Sir Thomas Neave, Bart. *F.S.A.* 6 Albemarle-street; and Dagnam-park, Rumford, Essex.
- Right Hon. Sir John Nicholl, Knt. D.C.L. *F.S.A. F.G.S.* 5 Audley-square; and Merthyr-mawr, Glamorganshire.
- Whitlock Nicholl, M.D. *M.R.I.A. F.L.S.* 18 Charles-street, Berkeley-square.
- Rev. Robert Nixon, B.D. *F.S.A. F.L.S.* Kenmure-castle, New Galloway, N.B.
- Rev. Frederick Nolan, LL.D. *M.R.S.L.* Prittlewell, Essex.
- Bernard Edward, Duke of Norfolk, E.M. *F.S.A.* 21 St. James's-square.
- Spencer Joshua Alwyne, Marquess of Northampton. Castle Ashby, Northampton.
- Hugh, Duke of Northumberland, K.G. M.A. *F.S.A. F.G.S.* Northumberland-house.
- James Adey Ogle, M.D. *F.R.A.S.* Lord Litchfield's, and Aldrich's, Professor of Medicine, Oxford. *Coll. Reg. Med. Socius.* Oxford.
- John Oldershaw, B.D. Archdeacon of Norfolk. Harlestone, Norfolk.
- Charles Savill Onley, Esq. *F.S.A. F.L.S.* 22 Great George-street, Westminster; and Stisted-hall, Essex.
- Horatio, Earl of Orford. Wolterton-park, Norfolk.
- George Ormerod, Esq. D.C.L. *F.S.A. F.G.S.* Sedbury-park, Gloucestershire; and Tildesley-house, Lancashire.
- Right Hon. Sir Gore Ouseley, Bart. G.C.H. *F.S.A. M.R.A.S. M.R.S.L. Acad. Imp. Sc. Petrop. Socius.* 49 Upper Grosvenor-street; and Woolmers, Hertfordshire.
- William, Lord Oxmantown, *F.R.A.S.* Birr-castle, King's County, Ireland.
- Sir Francis Palgrave, K.H. *F.S.A.* 26 Duke-street, Westminster.
- Henry Robinson Palmer, Esq. 18 Fludyer-street, Westminster.
- John Ayrton Paris, M.D. *F.L.S. Coll. Reg. Med. Socius.* 28 Dover-street.
- Woodbine Parish, jun. Esq. *F.S.A. F.G.S.* 5 Gloucester-place, Grosvenor-square.
- Thomas Lister Parker, Esq. *F.S.A. F.L.S.* 34 Mount-street.
- Charles Henry Parry, M.D. Bath.
- Sir William Edward Parry, Knt. D.C.L. Captain in the Royal Navy. *F.R.A.S. Acad. Imp. Sc. Petrop. Socius.* New South Wales.
- Colonel Charles William Pasley, Royal Engineers. Chatham.
- Rev. George Peacock, M.A. *F.G.S. F.R.A.S.* Trinity-college, Cambridge.
- Rev. William Pearson, LL.D. *V.P.R.A.S.* 6 Compton-terrace, Islington; and South Kilworth, near Welford, Northamptonshire.
- William Pearson, Esq. Clapham.

- Sir Samuel John Brooke Pechell, Bart.
Captain in the Royal Navy. Admiralty.
Right Hon. Sir Robert Peel, Bart. D.C.L.
F.S.A. Whitehall-gardens; and Drayton-
park, Fazeley, Staffordshire.
George Pemberton, Esq. 45 Edgeware-road;
and Bainbridge Holme, Durham.
Edward William Wynne Pendarves, Esq.
M.A. F.G.S. 36 Eaton-place, Belgrave-
square; and Pendarves, Truro, Cornwall.
Richard Penn, Esq. 6 Whitehall.
David Pennant, Esq. *F.L.S.* Downing, near
Holywell, Flintshire.
William Hasledine Pepys, Esq. *F.L.S.*
Poultry.
Herbert Marsh, Lord Bishop of Peterbo-
rough; Margaret Professor of Divinity,
Cambridge. *F.S.A.* Peterborough-palace,
Northampton.
Louis Hayes Petit, Esq. *M.A. F.S.A. F.L.S.*
F.G.S. F.R.A.S. M.R.S.L. 9 New-square,
Lincoln's-inn.
William Francis Henry, Lord Petre. 3 Mans-
field-street; and Thorndon-hall, near Brent-
wood, Essex.
Thomas Joseph Pettigrew, Esq. *F.S.A.*
F.L.S. M.R.A.S. Univ. Gotting. Phil.
Doct.—Acad. Reg. Divion. Socius. 8 Sa-
ville-street.
John Delafield Phelps, Esq. *F.S.A.* 11 New-
square, Lincoln's-inn; and Chavenage-house,
Tetbury, Gloucestershire.
Alexander Philip Wilson Philip, M.D.
F.R.S.E. 18 Cavendish-square.
Sir Thomas Phillipps, Bart. *M.A. F.S.A.*
F.L.S. F.G.S. M.R.S.L. 14 Stratford-
place; and Middle-hill, Worcestershire.
Charles Phillips, Esq. Captain in the Royal
Navy. H. M. S. *Ariadne*.
Richard Phillips, Esq. *F.R.S.E.* New Kent-
road.
- Thomas Phillips, Esq. *R.A. F.S.A.* 8 George-
street, Hanover-square.
Lewis Pinto de Souza Coutinho, K.G.F.
Acad. Reg. Sc. Olyssip. Socius.
William Morton Pitt, Esq. 22 Dover-street;
and Kingston-house, Dorchester.
Sir George Pocock, Bart. Bransgore-house,
Ringwood, Hampshire.
William Pole, Esq. *M.A.* 3 Stone-buildings,
Lincoln's-inn.
David Pollock, Esq. *F.R.A.S.* Dartmouth-
house, Westminster.
Frederick Pollock, Esq. *M.A. F.S.A. F.G.S.*
Queen-square-house, Guilford-street.
John Pond, Esq. Astronomer Royal.
F.R.A.S. Instit. Reg. Sc. Paris. Corresp.
—Socc. Reg. Sc. Gotting., et. Amer. Philad.,
Socius. Royal Observatory, Greenwich.
Hon. William Francis Spencer Ponsonby.
20 St. James's-square.
Rev. Baden Powell, M.A. Savilian Professor
of Geometry, Oxford. Oxford.
James Cowles Prichard, M.D. Bristol.
James Prinsep, Esq. Benares.
William Prout, M.D. *Coll. Reg. Med. Socius.*
40 Sackville-street.
Algernon, Lord Prudhoe. *F.S.A.* 37 Albe-
marle-street; and Stanwick-park, Darlington,
Yorkshire.
Philip Pusey, Esq. 45 Grosvenor-square;
and Pusey-house, near Farringdon, Berk-
shire.
Rev. Thomas Rackett, M.A. *F.S.A. F.L.S.*
48 Upper Gower-street; and Poole, Dor-
setshire.
John Ramsbottom, Esq. 1, F. Albany; and
Woodside, near Windsor.
William Rashleigh, Esq. *F.L.S.* 3 Cum-
berland-terrace, Regent's-park; and Mena-
billy-house, Foy, Cornwall.

John Reeves, Esq. *F.L.S. F.R.A.S.* Clapham.

George Rennie, Esq. 21 Whitehall-place.

Sir John Rennie, Knt. 15 Whitehall-place.

John Richardson, M.D. *F.L.S.* Royal Marine Infirmary, Chatham.

Charles Milner Ricketts, Esq. *F.G.S.* Lima.

John Rickman, Esq. M.A. 12 New Palace-yard.

Stephen Peter Rigaud, Esq. M.A. Savilian Professor of Astronomy, and Professor of Experimental Philosophy, Oxford. Richmond, Surrey; and Oxford.

Frederick John, Earl of Ripon. Carlton-gardens.

Rev. William Ritchie, LL.D. Professor of Natural Philosophy in the Royal Institution of Great Britain. 38 Devonshire-street, Portland-place.

Isaac Robinson, Esq. 30 Park-road, Regent's-park.

Samuel Rogers, Esq. *F.S.A.* 22 St. James's-place.

John Rogerson, M.D.

Peter Mark Roget, M.D.—*SECRETARY.*—*F.G.S. F.R.A.S. Coll. Reg. Med. Socius.* 39 Bernard-street, Russell-square.

Hon. Frederick de Roos, Captain in the Royal Navy. *F.R.A.S.* 106 Piccadilly.

Archibald John, Earl of Rosebery. 139 Piccadilly.

Captain Daniel Ross. India.

James Clark Ross, Esq. Commander in the Royal Navy. *F.R.A.S.* 13 Prince's-street, Cavendish-square.

Rev. George Rowley, D.D. Oxford.

Edward Rudge, Esq. *F.S.A. F.L.S.* 44 Wimpole-street; and Abbey Manor-house, Evesham, Worcestershire.

Jesse Watts Russell, Esq. D.C.L. *F.S.A.*

F.L.S. F.G.S. 169 New Bond-street; and Ilam-hall, Ashbourn, Derbyshire.

Sir William Russell, Bart. M.D. K.S.A. *Acad. Imp. Sc. Petrop. Socius Honor.* 13 York-place, Portman-square.

Edward Sabine, Esq. Captain in the Royal Artillery. *F.L.S. Acad. Imp. Sc. Petrop. : Socc. Reg. Sc. Norv., et Phil. Nov.-Ebor., Socius.—Acad. Reg. Sc. Brux. : Socc. Reg. Sc. Gotting., et Geogr. Paris., Corresp.* Limerick, Ireland.

Joseph Sabine, Esq. *F.S.A. F.L.S. Acad. Cæs. Nat. Cur. : Socc. Cæs. Nat. Cur. Mosc., Reg. Econ. Boruss., Reg. Bot. Ratisb., Phil. Nov.-Ebor., Socius.* 15 Mill-street, Conduit-street.

Michael Thomas Sadler, Esq. Leeds.

Sir John St. Aubyn, Bart. *F.S.A. F.L.S.* Clowance, Cornwall.

Count Jerome de Salis. 5 Carlton-gardens; and Rokeby, Dunlear, Ireland.

Thomas Burgess, Lord Bishop of Salisbury. *F.S.A.* 19 Devonshire-place; and Salisbury-palace, Wiltshire.

Rev. Thomas Sampson, D.D. *F.S.A.* Petersham, Surrey.

Edward Ayshford Sandford, Esq. Nynehead.

Rev. Augustus Page Saunders, M.A. Charter-house School.

George Saunders, Esq. *F.S.A.* 252 Oxford-street.

Henry Barne Sawbridge, Esq.

Rev. William Scoresby. *F.R.S.E. Instit. Reg. Sc. Paris. Corresp.* Exeter.

John Corse Scott, Esq.

George Poulett Scrope, Esq. *F.G.S.* Castle Combe, Chippenham, Wiltshire.

Sir Charles Scudamore, Knt. M.D. 6 Wimpole-street.

- Rev. John Barlow Seale, D.D. *F.S.A.* Stisted, near Braintree.
- Rev. Adam Sedgwick, M.A. Woodwardian Lecturer, Cambridge. *F.R.A.S.* Cambridge.
- Thomas James, Earl of Selkirk. St. Mary's Isle, Kirkcudbright.
- Henry John, Lord Selsey. 23 Grosvenor-street; and West Dean-house, Midhurst, Sussex.
- Sir Robert Seppings, Knt.
- Richard Sharp, Esq. *F.S.A.* 23 Park-lane; and Fridley Farm, Dorking, Surrey.
- John Sharpe, Esq. *F.S.A.* Richmond-green, Surrey.
- Sir Martin Archer Shee, Knt. President of the Royal Academy. 32 Cavendish-square.
- Rev. Richard Sheepshanks, M.A. *F.G.S. F.R.A.S.* 30 Woburn-place.
- Charles Short, Esq. *F.S.A.* 35 Great George-street, Westminster; and Woodlands, Emsworth, Hampshire.
- Sir Francis Shuckburgh, Bart. Pavilion, Hans-place, Chelsea; and Shuckburgh-park, Warwickshire.
- Richard Simmons, Esq. *F.S.A. F.L.S.* 2, F. Albany.
- Right Hon. Sir John Sinclair, Bart. D.C.L. *F.R.S.E. M.B.L.A. F.S.A. F.L.S.* Ulbster, Caithness.
- Rev. John Sleath, D.D. *F.S.A.* St. Paul's-school.
- John Smirnov, Esq. *F.L.S. Soc. Cæs. Nat. Cur. Mosc. Socius.* 80 Wimpole-street.
- Major Charles Hamilton Smith. Plymouth.
- James Smith, Esq. *F.R.S.E.* Jordan-hill, near Glasgow.
- John Spenser Smith, Esq. *F.S.A.* Caen, Normandy.
- Joseph Smith, Esq. *F.L.S.* 1 Field-court, Gray's-inn.
- Matthew Smith, Esq. Captain in the Royal Navy. Blackheath.
- Sir William Smith, Knt.
- William Smith, Esq. *F.S.A. F.L.S.* 5 Blandford-square, New-road.
- Admiral Sir William Sidney Smith, K.C.B. Paris.
- William Henry Smyth, Esq. Captain in the Royal Navy, K.S.F. *For. Sec. R.A.S.* The Observatory, Bedford.
- Thomas Snodgrass, Esq. 10 Chesterfield-street.
- Sir John Soane, Knt. R.A. *F.S.A.* 13 Lincoln's-inn-fields.
- Richard Horsman Solly, Esq. M.A. *F.S.A. F.L.S. F.G.S.* 48 Great Ormond-street.
- Samuel Solly, Esq. 48 Upper Gower-street.
- Samuel Reynolds Solly, Esq. M.A. *F.S.A. F.G.S.* Surge-hill, King's Langley, Hertfordshire.
- Edward Adolphus, Duke of Somerset, D.C.L. *F.S.A. F.L.S.*—President of the Royal Institution of Great Britain. Park-lane.
- William Somerville, M.D. *F.R.S.E. F.L.S. F.G.S.* Royal Hospital, Chelsea.
- William Sotheby, Esq. *F.S.A. F.G.S.*
- Sir James South, Knt. *F.R.S.E. M.B.L.A. F.L.S. F.R.A.S. Acad. Imp. Sc. Petrop. Socius; Acad. Reg. Sc. Brux. Corresp.* The Observatory, Camden-hill, Kensington.
- Henry Herbert Southey, M.D. *Coll. Reg. Med. Socius.* 1 Harley-street.
- William Speer, Esq. *F.S.A.* Great Queen-street, Westminster.
- George John, Earl Spencer, K.G. LL.D. *Trust. Brit. Mus. F.S.A.* 27 St. James's-place.

- Philip Henry, Earl Stanhope, 12 Albemarle-street; and Chevening-place, Kent.
- John Spencer Stanhope, Esq. *Inst. Reg. Sc. Paris. Corresp.*
- Edward Stanley, Esq. 12 Lincoln's-inn-fields.
- Sir John Thomas Stanley, Bart. *F.S.A.* 38 Brook-street.
- Sir George Thomas Staunton, Bart. *D.C.L. F.S.A. F.L.S.* 17 Devonshire-street, Portland-place.
- Archibald John Stephens, Esq. *M.A.* 61 Chancery-lane; and Eglantine Cottage, Surrey.
- John Robert Steuart, Esq. *M.R.A.S.* 56 North Frederick-street, Edinburgh.
- William Ford Stevenson, Esq. *F.S.A.* Grand-rue, Passy, near Paris.
- Charles Stokes, Esq. *F.S.A. F.L.S. F.G.S. F.R.A.S.* 4 Verulam-buildings.
- John Storer, M.D. Lenton Firs, near Nottingham.
- Anthony Mervin Reeve Storey, Esq. *M.A.* 85 Jermyn-street; and Glanusk, Brecon.
- Sir Edward Stracey, Bart. *LL.D.* 21 Great George-street, Westminster.
- Percy Clinton Sydney, Viscount Strangford, G.C.B. G.C.H. *F.S.A.* 68 Harley-street.
- Hon. William Thomas Horner Fox Strangways.
- William Samuel Stratford, Esq. Lieutenant in the Royal Navy. *F.R.A.S.* Superintendent of the Nautical Almanac. 3 Verulam-buildings, Gray's-inn; and 6 Notting-hill-square, Kensington.
- Major-General Sir Joseph Straton, Knt. C.B. *F.R.S.E.*
- George Frederick Stratton, Esq. *LL.D. F.S.A.* Tew-park, Deddington.
- George Holme Sumner, Esq. *F.S.A.* Hatchlands, Guildford, Surrey.
- Alexander Robert Sutherland, M.D. *F.G.S.* 1 Parliament-street; and Hermitage, Brompton.
- William Swainson, Esq. *F.L.S. Soc. Hist. Nov.-Ebor. Socius.—Soc. Hist. Nat. Paris. Corresp.* Tittenhanger-green, near St. Alban's.
- Sir John Edward Swinburne, Bart. *F.S.A.* 18 Grosvenor-place.
- Charles Chetwynd, Earl Talbot, K.P. *F.S.A.* 71 Grosvenor-street; and Ingestrie-hall, near Stafford.
- Christopher Rice Mansel Talbot, Esq. 63 St. James's-street; and Margam, Glamorganshire.
- Henry Fox Talbot, Esq. 31 Sackville-street; and Lacock-abbey, near Chippenham.
- John Taylor, Esq. *Treas. G.S.* 12 Bedford-row.
- George Watson Taylor, Esq. *F.S.A.*
- Thomas Telford, Esq. *F.R.S.E. F.G.S. F.R.A.S.* 24 Abingdon-street, Westminster.
- Right Hon. Charles Tennyson. *F.S.A.* 4 Park-street, Westminster.
- Honoratus Leigh Thomas, Esq. 12 Leicester-place.
- Lieut-Colonel Thomas Perronet Thompson, M.A. 2 King-street, Portman-square.
- James Thomson, Esq. Primrose, near Clitheroe.
- John Thomson, M.D. *F.R.S.E.* 80 George-street, Edinburgh.
- Sir John Deas Thomson, K.C.H. *F.L.S.*
- Thomas Thomson, M.D. Regius Professor of Chemistry, Glasgow. *F.R.S.E. F.L.S. F.G.S.* Glasgow.
- Right Hon. Sir Edward Thornton, G.C.B. Wembury, Plymouth.
- Rev. George Augustus Thursby, M.A. *F.L.S.* 76 Wimpole-street; and Penn, near Wolverhampton, Staffordshire.
- Dr. John Lewis Tiarks. *F.R.A.S. Soc.*

- Phil. Nov.-Ebor., et Amer. Philad., Socius.*
Jever, Hanover.
- Robert Stearne Tighe, Esq. *F.S.A.*
William Edward Tomline, Esq. 1 Carlton-house-terrace; and Rigby-grove, near Brigg, Lincolnshire.
- Thomas Tooke, Esq.
William Tooke, Esq. *M.R.S.L.* 12 Russell-square.
- Lieut.-Colonel Robert Torrens. 12 Fludyer-street, Westminster.
- George Townley, Esq. 179 Piccadilly.
- Rev. John Montgomery Traherne, M.A. *F.L.S. F.G.S.* St. Hilary, near Cowbridge, Glamorganshire.
- Benjamin Travers, Esq. 12 Bruton-street.
- Edward Troughton, Esq. *F.R.S.E. V.P.R.A.S.* 136 Fleet-street.
- Charles Augustus Tulk, Esq. *F.S.A.* 19 Duke-street, Westminster.
- Peter Evan Turnbull, Esq. *F.S.A.* 68 Baker-street.
- Rev. Thomas Smith Turnbull, M.A. Caius-college, Cambridge.
- Charles Hampden Turner, Esq. *F.L.S. F.G.S.* 15 Bruton-street; and Rook's Nest, Godstone, Surrey.
- Dawson Turner, Esq. *Hon. M.R.I.A. F.S.A. F.L.S. M.R.S.L. Acad. Cæs. Nat. Cur., et Reg. Sc. Holm., Socius.* Yarmouth.
- Edward Turner, M.D. *F.R.S.E. Sec. G.S.* 38 Upper Gower-street.
- Samuel Turner, Esq. Liverpool.
- Sir George Leman Tuthill, Knt. M.D. *Coll. Reg. Med. Socius.* 24 Cavendish-square.
- Lieut.-Col. Sir John Maxwell Tylden, Knt. Milsted, Kent.
- Andrew Ure, M.D. *F.R.A.S.* Professor of Physics in the Andersonian University, Glasgow. 13 Charlotte-street, Bedford-square.
- William Vaughan, Esq. *F.L.S. F.R.A.S.* 70 Fenchurch-street.
- Baron Nicholas Vay de Vaja.
- Captain James Vetch.
- Nicholas Aylward Vigors, Esq. D.C.L. M.A. *M.R.I.A. F.S.A. F.L.S.* 16 Chester-terrace, Regent's-park.
- John Henry Vivian, Esq. *F.G.S.* Swansea, Glamorganshire.
- Sir Richard Rawlinson Vyvyan, Bart. 26 Great George-street, Westminster; and Trelowarren, Cornwall.
- James Walker, Esq. *F.R.S.E.* 23 Great-George-street, Westminster.
- Rev. Robert Walker, M.A. Wadham-college, Oxford.
- Charles Baring Wall, Esq. M.A. *F.S.A. M.R.S.L.* 44 Berkeley-square; and Norman-court, near Stockbridge, Hampshire.
- Nathaniel Wallich, M. et Ph. D. *F.R.S.E. F.L.S. F.G.S. M.R.A.S. Inst. Reg. Sc. Paris. Corresp.—Acad. Reg. Sc. Hafn. Socius.* India.
- Rev. Henry Walter, B.D. Hasilbury Bryan, Dorsetshire.
- Henry Warburton, Esq. M.A. *V.P.G.S.* 45 Cadogan-place, Sloane-street.
- John Ashley Warre, Esq. 7 Belgrave-square.
- Rev. John Warren, M.A. Gravely, Cambridgeshire.
- Pelham Warren, M.D. *Col. Reg. Med. Socius.* 31 Brook-street.
- Right Hon. Sir George Warrender, Bart. *F.R.S.E.* 22 Albemarle-street.
- Sir Frederick Beilby Watson, K.C.H. *F.S.A.*
- Ralph Watson, Esq. *F.S.A.* 14 York-place, Portman-square.
- James Watt, Esq. Soho, Birmingham.
- Major-General Arthur Goodall Wavell, K.F. K.C.S.

- Thomas Weaver, Esq. *M.R.I.A. F.G.S.* Mexico.
- Frederick Webb, Esq. *F.S.A.* Brighton.
- Sir Charles Wetherell, Knt. *M.A.* 7 Whitehall-place.
- John Weyland, Esq. 52 Charles-street, Berkeley-square; and Woodrising-hall, Norfolk.
- Rev. William Whewell, *M.A. F.G.S. F.R.A.S.* Trinity-college, Cambridge.
- John Whishaw, Esq. *M.A. F.S.A. F.G.S.* 51 Lincoln's-inn-fields.
- George Wilbraham, Esq. 56, Upper Seymour-street; and Delamere-house, Northwich, Cheshire.
- Sir Charles Wilkins, *K.H. LL.D. M.R.A.S. Instit. Reg. Sc. Paris., et Acad. Reg. Monach., Socius.* 40 Baker-street, Portman-square.
- William Wilkins, Esq. *R.A.* 35, Weymouth-street; and Lensfield, Cambridge.
- John Lloyd Williams, Esq. Alderbrook-hall, Cardiganshire.
- John Williams, jun. Esq. *F.L.S.* Scorrier-house, near Redruth, Cornwall.
- Rev. Robert Willis, *M.A.* Cambridge.
- Sir John Eardley Eardley Wilmot, Bart. *D.C.L. F.S.A. F.L.S.* 6 York-place, Portman-square; and Berkswell-park, near Coventry.
- Sir Giffin Wilson, Knt. 2 Stratford-place; and Wooburn-house, Beaconsfield, Buckinghamshire.
- Glocester Wilson, Esq. Hastings.
- Isaac Wilson, *M.D.* Royal Hospital, Haslar, Portsmouth.
- Rev. Samuel Wix, *M.A. F.S.A.* St. Bartholomew's-hospital.
- William Wix, Esq. Tunbridge Wells.
- Alexander Luard Wollaston, Esq. *M.B. F.R.A.S.* 3 Elm-court, Temple; and Clapham-common.
- William Wood, Esq. *F.L.S.* 39 Tavistock-street, Covent-garden.
- John Woolmore, Esq. 15 Bruton-street; and Hampton, Middlesex.
- Robert James Carr, Lord Bishop of Worcester. Worcester-palace.
- Hon. John Stuart Wortley, *B.A.* 77 South Audley-street.
- Francis Wrangham, *M.A.* Archdeacon of Cleveland.
- Sir Jeffry Wyatville, Knt. *F.S.A. F.G.S.* 50 Brook-street.
- Grant David Yeats, *M.D. Coll. Reg. Med. Socius.* Meadow-hill, Tunbridge Wells.
- John Yelloly, *M.D. F.G.S. Soc. Phil. Nov.-Ebor. Socius.* Woodton-hall, Norfolk.
- Right Hon. Charles Philip Yorke. *F.S.A.* 28 Bruton-street; and Bonningtons, near Ware, Hertfordshire.

FOREIGN

FOREIGN MEMBERS.

Adam Afzelius	<i>Upsal.</i>	1798.	Baron Alexander von Humboldt	<i>Berlin.</i>	1815.
André-Marie Ampère	<i>Paris.</i>	1827.	C. G. J. Jacobi	<i>Königsberg.</i>	1833.
François-Jean-Dominique Arago	<i>Paris.</i>	1818.	Antoine-Laurent de Jussieu . .	<i>Paris.</i>	1829.
Don Felipe Bauzá	<i>Madrid.</i>	1819.	Baron von Lindenau	<i>Gotha.</i>	1833.
Jens Jacob Berzelius	<i>Stockholm.</i>	1813.	Joseph-Louis Gay-Lussac . . .	<i>Paris.</i>	1815.
Friedrich Wilhelm Bessel . . .	<i>Königsberg.</i>	1825.	Martin van Marum	<i>Haarlem.</i>	1798.
Jean-Baptiste Biot	<i>Paris.</i>	1815.	Eilert Mitscherlich	<i>Berlin.</i>	1828.
H. M. Ducrotay de Blainville . .	<i>Paris.</i>	1832.	Domenico Morichini	<i>Rome.</i>	1827.
Johann Friedrich Blumenbach .	<i>Göttingen.</i>	1793.	Jens Christian Oersted	<i>Copenhagen.</i>	1821.
Alexis Bouvard	<i>Paris.</i>	1826.	Wilhelm Olbers	<i>Bremen.</i>	1804.
Nathaniel Bowditch	<i>Boston.</i>	1818.	Giovanni Plana	<i>Turin.</i>	1827.
Alexandre Brongniart	<i>Paris.</i>	1815.	Le baron Poisson	<i>Paris.</i>	1818.
Leopold von Buch	<i>Berlin.</i>	1828.	G. de Pontécoulant	<i>Paris.</i>	1833.
Auguste-Pyrame de Candolle . .	<i>Geneva.</i>	1822.	Pierre Prévost	<i>Geneva.</i>	1806.
Francesco Carlini	<i>Milan.</i>	1832.	Le baron de Prony	<i>Paris.</i>	1818.
Le Comte de Cassini	<i>Paris.</i>	1789.	Théodore de Saussure	<i>Geneva.</i>	1820.
Augustin-Louis Cauchy	<i>Paris.</i>	1832.	Heinrich Christian Schumacher	<i>Altona.</i>	1821.
Michel-Eugène Chevreul	<i>Paris.</i>	1826.	Friedrich Stromeyer	<i>Göttingen.</i>	1827.
Le baron de Damoiseau	<i>Paris.</i>	1832.	Friedrich Georg Wilhelm Struve	<i>Dorpat.</i>	1827.
Pierre-Louis Dulong	<i>Paris.</i>	1826.	Friedrich Tiedemann	<i>Heidelberg.</i>	1832.
Johann Friedrich Encke	<i>Berlin.</i>	1825.	Le baron Thénard	<i>Paris.</i>	1824.
Paul Erman	<i>Berlin.</i>	1827.	*		
Karl Friedrich Gauss	<i>Göttingen.</i>	1804.	*		
Karl Ludwig Harding	<i>Göttingen.</i>	1806.	*		
Simon L'Huilier	<i>Geneva.</i>	1791.	*		

PRINTED BY RICHARD TAYLOR,
RED LION COURT, FLEET STREET.





1-54
R2



